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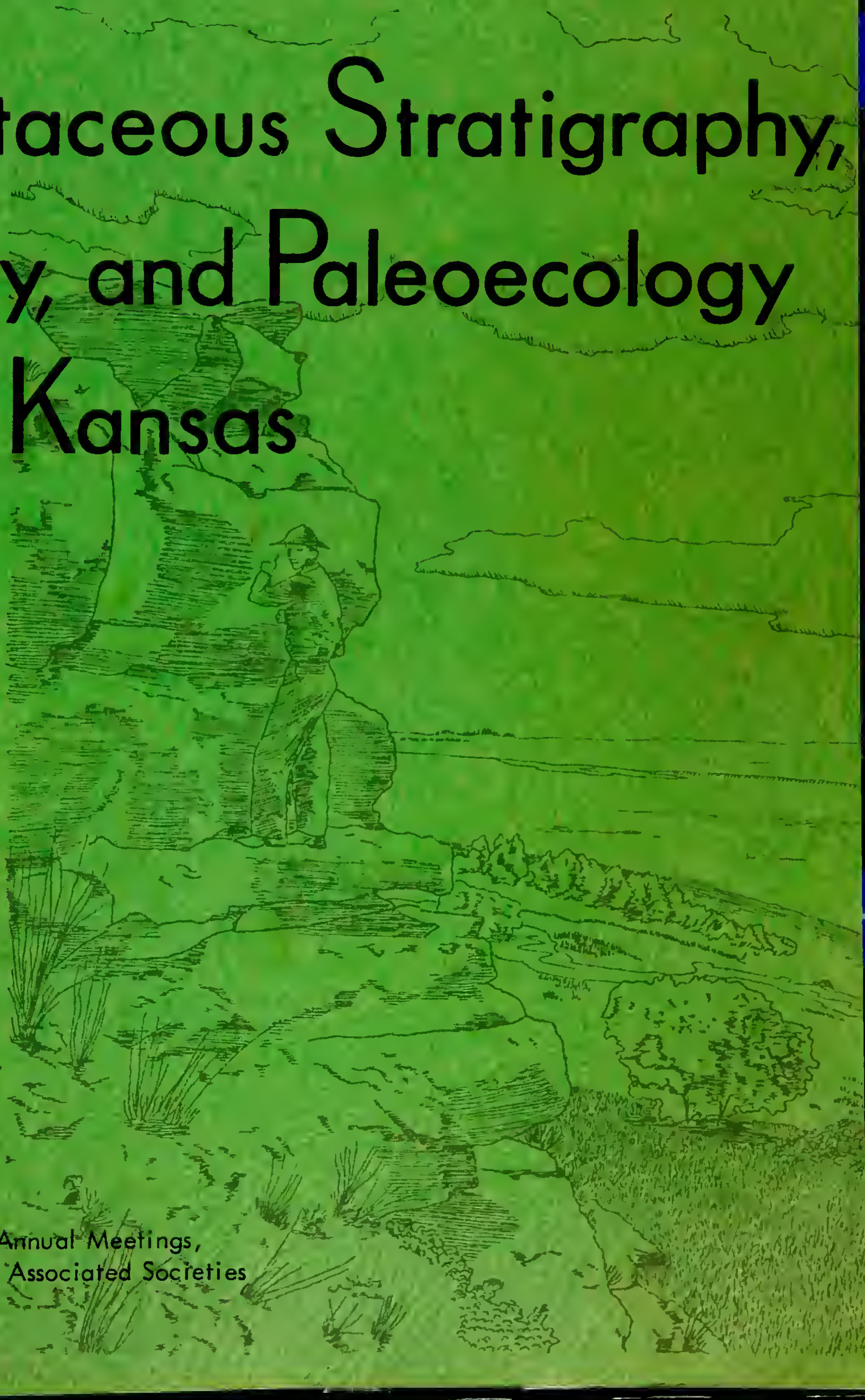
State Geological Survey of Kansas
The University of Kansas, Lawrence, Kansas

Upper Cretaceous Stratigraphy, Paleontology, and Paleoecology of Western Kansas



A Field Conference Guidebook for the Annual Meetings,
The Geological Society of America and Associated Societies
Kansas City, Missouri, 1965

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Gary F. Stewart
State Geological Survey of Kansas

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by

Donald E. Hattin, Indiana University

assisted by

William A. Cobban, U. S. Geological Survey

CONTENTS

Page

Introduction. 1

  Objectives of trip 1

  Acknowledgments. 1

  Historical account 2

Physiography. 4

  Smoky Hills. 4

  High Plains. 5

  Development of present topography. 6

Structure 7

General stratigraphy. 9

Descriptions of Cretaceous units in field-trip area 9

  Dakota Formation 9

  Graneros Shale 12

  Greenhorn Limestone. 14

  Carlile Shale. 16

  Niobrara Chalk 20

  Pierre Shale 22

Late Cretaceous cyclic sedimentation in western Kansas. 26

References. 27

Road logs 29

Appendix. 48

UPPER CRETACEOUS STRATIGRAPHY, PALEONTOLOGY, AND PALEOECOLOGY OF WESTERN KANSAS

by

Donald E. Hattin

INTRODUCTION

Objectives of the Trip

Spectacular fossils in Upper Cretaceous rocks of western Kansas have excited paleontologists for nearly a century and have lured generations of enthusiastic collectors to concretion-strewn shale slopes and chalk badlands that break the monotony of the Great Plains. For decades, writers of historical geology textbooks have embellished their chapters on the Cretaceous with illustrations of the mosasaurs, pterosaurs, cephalopods, pelecypods, crinoids, and plant remains that have earned the Kansas Cretaceous a place of enduring fame in the annals of American paleontology. From earliest beginnings in fossil collection and description, study of these rocks evolved to a stage of mapping and description of strata which is now giving way to studies devoted to petrogenesis, paleoecology, and refinements in biostratigraphy.

This field excursion is designed to acquaint participants with details of the vertical succession of marine Upper Cretaceous strata in Kansas and to afford opportunity for collecting representative suites of invertebrate fossils from each rock unit. To this end a group of remarkable exposures has been selected for examination of a complete section extending from the upper part of the Dakota Formation upward into the lower part of the Niobrara Chalk. Additional exposures to be visited are representative of the upper part of the Niobrara and lower part of the Pierre Shale. At each stop discussion will center on critical aspects of lithostratigraphy, biostratigraphy, paleoecology, and general depositional history of the units exposed.

Acknowledgments

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Historical Account

The earliest classification of Cretaceous strata in the Western Interior Region was by Hall and Meek (1856, p. 405) who subdivided the Missouri River section of Nebraska into units numbered 1 through 5, from the base upward. Geographic names based on places of typical exposure of these subdivisions were subsequently published by Meek and Hayden (1861, p. 419) in a comprehensive tabulation that included lithologic and paleontologic descriptions and thicknesses for each of the five formations. The names assigned were as follows:

Formation No. 5 - Fox Hills
Formation No. 4 - Pierre
Formation No. 3 - Niobrara
Formation No. 2 - Fort Benton
Formation No. 1 - Dakota

Cretaceous rocks were mapped in Kansas as early as 1857 (Hayden) but detailed study proceeded slowly as evident in the remark by Swallow (1866, p. 10), in his first annual report as State Geologist of Kansas, that the "...Cretaceous is represented rather largely, but no definite examination has been made to show its extent, as it lies mostly beyond the settlements. Chalk is said to have been found in it."

During the early 1870's, four expeditions led by O. C. Marsh and one by E. D. Cope entered the rich fossil field of western Kansas for the purpose of collecting vertebrate remains. From this work sprang a great volume of literature on fish, reptiles, and birds of the Niobrara Chalk, and a new generation of vertebrate paleontologists.

In 1872, Hayden published one of the first detailed accounts of Cretaceous rocks in Kansas following a train trip on the Union Pacific railroad, which included the area between Salina and Fort Wallace. Although Hayden recognized Formations No. 1, 2, and 3 in this work, Mudge (1875, p. 111) claimed that the Benton Group (No. 2) appeared to be absent in Kansas and stated further, "Hostile Indians and an uninviting country have kept explorers from traversing the southwestern plains." Shortly thereafter, Mudge (1878) not only recognized the presence of the Fort Benton but included in it the Fort Hays Limestone (now a member of the Niobrara Chalk). During this period Meek examined some Kansas baculitids that Mudge claimed were collected from the Niobrara. Meek suspected that the specimens came from Formation No. 4 or No. 5 (Pierre or Fox Hills)* but Mudge persisted in his belief that the baculitid beds in question were Niobrara. Ultimately, the beds containing the baculitids were referred to the Pierre Shale by Williston (1893).

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*These baculitids were collected at a locality near McAllaster, Kansas. Stop No. 6 of our trip is in the Pierre Shale at McAllaster.

During the last decade of the 19th Century, considerable attention was focused upon the classification and description of Cretaceous rocks in western Kansas. Some rock unit names proposed during this time were synonyms and were discarded (i.e., Lisbon for Pierre; Osborne for Fort Hays), some were nongeographic in origin (i.e., Bituminous Shale horizon for Graneros; Hesperornis beds for part of the Smoky Hill), and some stand to this day (i.e., Blue Hill; Lincoln). In 1896, G. K. Gilbert divided the Benton into three formations (Graneros Shale, Greenhorn Limestone, and Carlile Shale) on the basis of exposures in the foothills of the Rocky Mountains of Colorado. Logan (1899) recognized equivalent units in the Kansas Benton, but Gilbert's names for these units were first used in the State by Darton (1904, pl. 36). Subdivision of formations and naming of member units in the Upper Cretaceous in Kansas has followed a rather haphazard course; one formal name appeared as early as 1876 (Fort Hays Limestone) and the latest appeared in 1942 (Janssen Clay Member of the Dakota Formation).

In 1897 and 1898, under the direction of Erasmus Haworth, work in western Kansas by the State Geological Survey culminated with publication of several major reports on the stratigraphy and paleontology of the Upper Cretaceous rocks. Through the years of the present century, shorter paleontological papers have appeared steadily and treat a broad spectrum of vertebrate, invertebrate, and paleobotanical subjects.

The next episode in the saga occurred in the mid-twenties and thirties when the State Geological Survey published a number of geological reports on several counties lying across the Cretaceous outcrop. Especially notable among these reports are those for Russell County (Rubey and Bass, 1925) and Wallace County (Elias, 1931). In more recent years, from about 1940 to date, brief summaries of Upper Cretaceous stratigraphy have accompanied a number of county reports concerned with geology and ground-water conditions within the Cretaceous outcrop in Kansas. Detailed stratigraphic reports have been published for the Dakota Formation (Plummer and Romary, 1942), Carlile Shale (Hattin, 1962), and Graneros Shale (Hattin, 1965, in press) and further studies of this kind are in progress. Other aspects of Cretaceous geology that have received attention recently include subsurface stratigraphy (Merriam, 1957a; Merriam and others, 1959), cross-stratification (Franks and others, 1959), and mineral commodities ranging from chalk to uranium.

Interest in Upper Cretaceous rocks of western Kansas shows no sign of decline, despite many years of study by a legion of investigators. Discoveries of new fossils occur frequently and many invertebrate species remain undescribed. Petrographic study of some rock units has scarcely begun, and geochemical analysis of both rocks and faunas is needed badly. Studies of depositional environment and paleoecology must be considered far from complete and offer much challenge for researchers in years to come.

PHYSIOGRAPHY

Smoky Hills

Cretaceous rocks of Kansas are confined to the Great Plains physiographic province which, in the part of the State described in this guidebook, is divided into two contrasting sections, the Smoky Hills to the east and the High Plains to the west (Fig. 1). During most of the first day we will be traveling across the Smoky Hills and during the second day we will be in the High Plains.

The Smoky Hills are composed of rocks belonging mainly to the Dakota Formation and lower part of the Colorado Group, and they are separated from the High Plains by a prominent escarpment capped by the Fort Hays Limestone Member of the Niobrara Chalk. The eastern half of the section is characterized by hilly topography developed on shale and sandstone units of Cretaceous rocks older than the Greenhorn Limestone. Prominent hills are held up by sandstone bodies within the stratigraphically complex Dakota Formation. The distinctive topographic aspect of this part of the section prompted Schoewe (1949) to restrict use of the name Smoky Hills thereto and to use the term Blue Hills for the western part of the section. Along the route of this excursion the most conspicuous development of this rough topography is south of Interstate Highway 70, just west of Brookville, where the landscape bears close resemblance to the "stagecoach country" of the familiar "Western" motion picture.

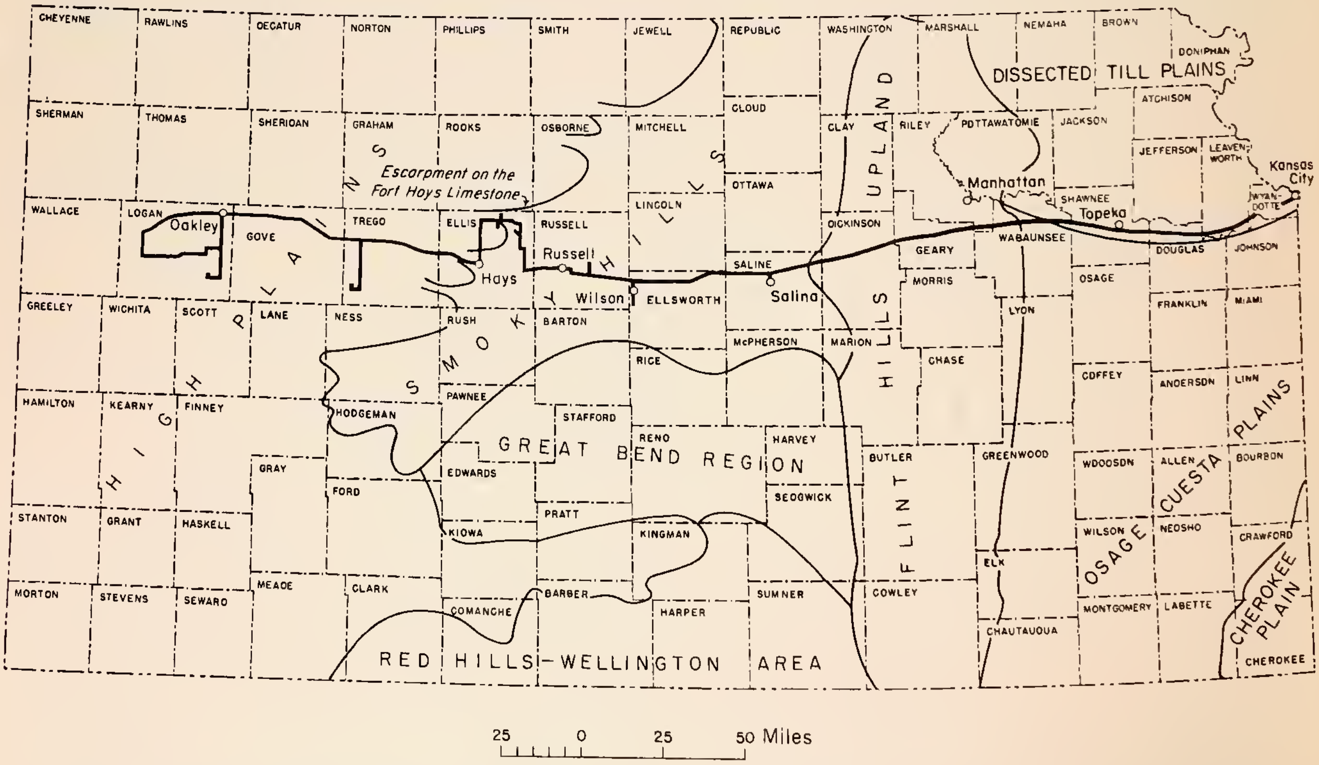


Figure 1.- Map showing physiographic divisions of Kansas (adapted from Frye and Schoewe, 1952). Route of field trip is indicated by heavy line.

The western half of the Smoky Hills section is bounded on the east by an escarpment capped by Greenhorn Limestone and on the west by the much bolder Fort Hays Escarpment. Both features are most prominent along Saline and Smoky Hill rivers and manifest progressively diminished relief away from these major stream courses. Upland topography is relatively flat where underlain by the upper part of the Greenhorn Limestone or lower part of the Carlile Shale, but toward the western edge of the Smoky Hills, steep slopes and local badlands are developed on the younger parts of the Carlile in bluffs, buttes, and small mesas capped by the Fort Hays Limestone Member.

In the part of the Smoky Hills section that we will see, maximum relief is near 300 feet along the Saline River and 150 feet along the Smoky Hill River. Terraces underlain by Pleistocene alluvium are preserved along major streams and some tributaries, but are more conspicuous in the valley of the Smoky Hill River. The upland surface is thinly veneered by Pleistocene loess. The lowest elevation along the route of the field trip is approximately 1570 feet above sea level and lies in the bed of Smoky Hill River at Stop 1.

High Plains

West of the Fort Hays Escarpment the High Plains section is underlain by Pierre Shale, Niobrara Chalk, Ogallala Formation, and various deposits of Pleistocene age. The uplands are, in general, monotonously flat owing largely to a widely distributed but discontinuous veneer of loess laid down during three episodes of eolian deposition that occurred during the Illinoisan and Wisconsinan Stages. Bedrock formations of Pliocene and Cretaceous age are exposed locally in the upland areas. Thousands of shallow depressions that dot the upland surface of the High Plains have been the subject of much discussion in the literature and have been attributed to the activity of buffaloes, wind, solution, compaction, and silt infiltration (Frye and Leonard, 1952, p. 203). In the western part of the region that we will cross during the second day, bedrock beneath the upland surface is largely that of the Ogallala Formation; farther east on our route this formation is thin, patchy, or absent, and Niobrara beds form nearly all of the upland bedrock.

In the area of this trip the High Plains surface is slashed by eastward- to southeastward-flowing streams of the Smoky Hill River drainage basin. Smoky Hill River valley is 15 miles or more wide where it cuts into soft deposits of the Smoky Hill Chalk Member and Pierre Shale in Gove and Logan counties. The inner valley, including low-level, late Pleistocene terraces and Recent flood plain, ranges in width from $\frac{1}{4}$ to 1 mile. In Logan and Gove counties, the outer parts of the valleys are characterized in many places by broad streamward-sloping, debris-veneered erosional surfaces that Frye and Leonard (1952, p. 27) called "flanking pediments." These surfaces are steepest at the valley edges, just below the upland margin, and downslope they flatten until they are nearly horizontal toward the inner valley, where they may merge with high-level terrace deposits (Johnson, 1958; Hodson and Wahl, 1960, p. 13). Cretaceous rocks crop out in bluffs that separate these terrace deposits and the inner valley, and also in areas where the outer valley slopes are not protected by flanking-pediment veneer. Exposures of the Smoky Hill Chalk Member are particularly susceptible to erosion by rain wash and streams and in a number of places this unit has been carved into badlands with steep-walled canyons, natural bridges, and slender pinnacles. Where dissection of the upper parts of valley slopes has exposed lithified Ogallala beds that underlie the upland surface, that formation holds up steep cliffs that are picturesque in their own right.

During the afternoon of the second day, we will cross the eastern edge of the High Plains in an area where the Ogallala Formation has been stripped by erosion from all but the highest divides, where the unit remains as thin discontinuous remnants nearly to the crest of the Fort Hays Escarpment. Most of the area is underlain by the Smoky Hill, which is thinly veneered by Pleistocene loess. Upland areas underlain by Ogallala deposits are generally flatter than those underlain by Cretaceous rocks.

Along the Smoky Hill River in Trego and Ellis counties a conspicuous high terrace known as Pfeifer Terrace lies 25 to 60 feet above the present flood plain and 60 to 120 feet below the upland surface (Leonard and Berry, 1961, p. 14). Remnants of flanking pediments, like those in Gove and Logan counties, locally slope down from the Fort Hays Escarpment and merge with this high terrace. Pfeifer Terrace has been traced from Ellsworth County, in the Smoky Hills, to as far west as Logan County in the High Plains (Frye and Leonard, 1952, p. 97). Deposits underlying the Pfeifer Terrace are assigned to the Kansan, Yarmouthian, and Illinoisan Stages of the Pleistocene Series. Near the eastern edge of the High Plains a lower terrace, lying only a few feet above the present flood plain along the inner valley of Smoky Hill River and some of its tributaries, is assigned a late Wisconsinan age by Leonard and Berry (1961, p. 48), who have traced the terrace westward to Logan County.

Development of Present Topography

Following final retreat of the Western Interior Sea, Cretaceous rocks in western Kansas were truncated during an erosional interval that produced, just prior to inception of Pliocene deposition, broad plains of low relief across which drainage was generally eastward in the area of our interest (Johnson, 1958, p. 28; Frye and Leonard, 1952, p. 185). Major uplift in the Rocky Mountains region brought a flood of detritus that filled valleys and buried divides beneath a complex of coalescent alluvial plains; these deposits levelled the existent topography and formed the monotonous topography that remains little modified in undissected areas of the High Plains.

Pleistocene erosion and alluviation along Smoky Hill River resulted in the formation of terrace deposits at three major levels. The following summary of Pleistocene events in the area of the field trip is drawn from the work of Frye and Leonard (1952) and Leonard and Berry (1961).

Moderate initial dissection of the High Plains occurred during the Nebraskan Stage, during which time the streams deposited alluvium now preserved as a terrace remnant lying less than 100 feet below the upland surface in the Smoky Hills of southwestern Ellis County. Deep downcutting during Kansan time resulted in alluviation along channels now preserved mostly beneath sediments of Illinoisan age in the Pfeifer Terrace. Valley broadening and alluviation during Illinoisan time is reflected in widespread sand, gravel, and silt deposits that form the upper part of Pfeifer Terrace. Remnants of a terrace of the same age are preserved along Saline River valley to the north. Renewed downcutting and alluviation during the Wisconsinan Stage produced the low river terraces. Post-Wisconsinan changes include cutting of the present channel into Wisconsinan deposits or Cretaceous bedrock, and development of the present narrow flood plain.

Widespread deposition of loess during the Illinoisan and Wisconsinan Stages has irregularly veneered the uplands, pediments, and older terraces, thus masking the relationships among these features in some areas.

STRUCTURE

Structural dip at the top of the Dakota Formation is approximately 7 feet per mile to the northeast in the easternmost portion of the field-trip area, increasing westward in Ellis and Trego counties to approximately 10 feet per mile to the north or slightly east of north. Still farther to the west, in Gove County, the dip is approximately 13 feet per mile to the north and increases further to approximately 20 feet per mile to the northeast in Logan County (see Merriam, 1957b). Major structural features reflected at this datum in western Kansas include, from east to west, the Salina Basin, Cambridge Arch, Western Kansas Basin and the eastern flank of the Las Animas Arch (Fig. 2). According to Merriam (1963) the Salina Basin and Cambridge Arch are largely inherited from an earlier structural framework, the Western Kansas Basin is a Mesozoic feature, and the Las Animas Arch in Kansas is largely a post-Cretaceous feature. The Cambridge Arch lies outside the area of this field excursion. Paleozoic structures in the area that are not reflected at the top of the Dakota include the Central Kansas Uplift, which underlies our route in Ellsworth, Russell, Ellis, and Trego counties, and the Hugoton Embayment which embraces all of Kansas west of the Cambridge Arch and Central Kansas Uplift (Merriam, 1963, p. 178).

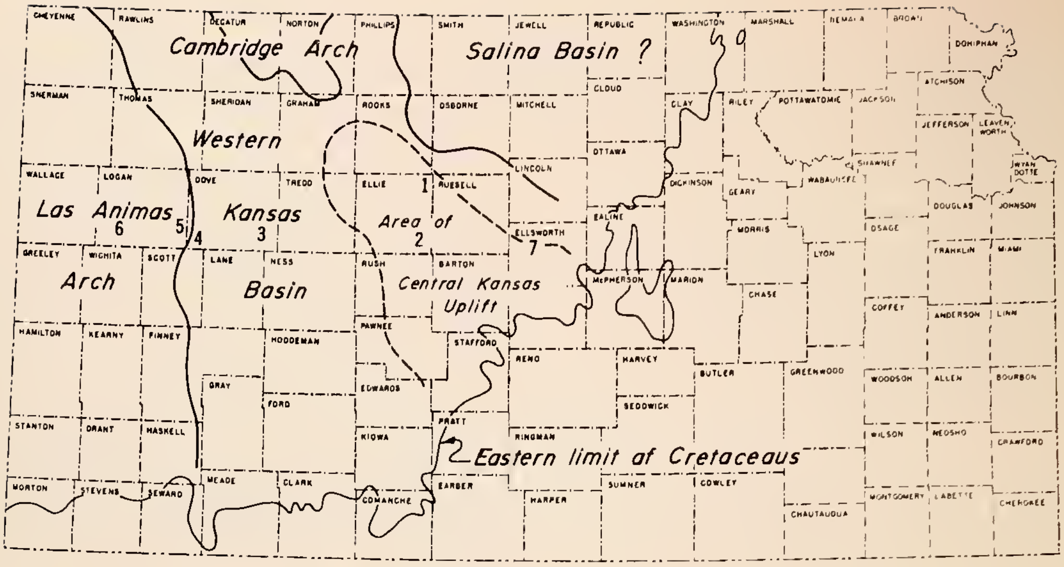


Figure 2.- Major structural features reflected in Cretaceous rocks in the field-trip area. Named minor structures are: (1) Fairport-Natoma Anticline, (2) Pfeifer Anticline, (3) Alanthus Dome, (4) Hell Creek Structure, (5) Elkader Dome, (6) Twin Buttes Anticline, (7) Ellsworth Anticline. Adapted from Merriam (1963, p. 178).

Named minor structures expressed in Cretaceous rocks in the field-trip area include the asymmetrical Fairport-Natoma Anticline in northeastern Ellis County; the Pfeifer Anticline of southeastern Ellis County, aligned with the Fairport-Natoma structure; Alanthus Dome in southeastern Gove County; the domelike Hell Creek structure in southern Gove, southeastern Logan and northeastern Scott counties; Elkader Dome in southeastern Logan County and Twin Buttes Anticline in southwestern Logan County (Jewett, 1951). Merriam (1963) also included the Ellsworth Anticline of northwestern Ellsworth County among minor structures reflected in Cretaceous rocks. The regional dip of the Cretaceous is further modified by numerous unnamed minor anticlines, synclines, and other structures which have been described by Lupton and others (1922), Rubey and Bass (1925), Bass (1926), Elias (1931), and Johnson (1958).

On a smaller scale, hundreds of normal faults that are best expressed in the Niobrara Chalk occur also in the Carlile and Pierre Shales. In a small area of northwestern Ellis County, Bass (1926, p. 44) mapped 76 faults, nearly all of which are in the Smoky Hill Chalk Member. Maximum displacement observed by Bass was 80 feet and the greatest length of trace among these faults was less than half a mile. Johnson (1958, p. 30) believed that displacement along some such faults in Logan County might exceed 200 feet and mapped the trace of one fault, or closely spaced set of faults, that is nearly 3½ miles in length. The Pierre Shale lies in fault contact with the Niobrara Chalk in a number of areas in Logan and Gove counties. Most of the faults in the field-trip area have dips of 45° ± 10°, although some are nearly vertical, and are marked by masses of slickensided calcite that may be very thin or several inches thick; but brecciation has occurred along some fault planes. Dip on beds directly adjacent to such faults was found to be as high as 15° by Johnson (1958, p. 30) and 19° by Bass (1926, p. 45). These faults are not believed to be related to regional structure.

In contrast to Cretaceous rocks, the Ogallala Formation is deformed only locally (Elias, 1931). Structure at the top of the "Algal limestone" marking the top of the formation is characterized by "monotonously uniform east dip, which reflects none of the major structural features in western Kansas" and averages approximately 15 feet per mile between the Colorado line and Mitchell and Lincoln counties (Merriam, 1963, p. 197).

GENERAL STRATIGRAPHY

Classification and characteristics of all stratigraphic units that crop out in the field-trip area are summarized in Table 1. Along the valley of the Smoky Hill River and its western tributaries exposed Upper Cretaceous marine rocks reach an aggregate thickness of approximately 1,670 feet. Of this thickness, about 600 feet are dark-gray noncalcareous shale belonging to the incompletely exposed Pierre Shale. The Colorado Group is approximately 1,060 feet thick, including 850 feet of limestone and chalk, 200 feet of dark-gray noncalcareous shale, 6 feet of quartzose sandstone and siltstone, and approximately 8 feet of bentonite. Sandstone locally comprising the uppermost 5 feet of the Dakota Formation is probably also of marine origin. Along the Saline River valley, the Colorado Group is approximately 995 feet thick, with 740 feet of limestone and chalk, 215 feet of noncalcareous shale, a maximum of 31 feet of sandstone and siltstone, and approximately 8 feet of bentonite. In addition, at least 22 feet of sandstone in the upper part of the Dakota Formation locally are of marine origin.

Cretaceous strata were truncated regionally by pre-Pliocene erosion, then buried beneath Ogallala deposits which, at one place or another in the State, rest on every one of the Cretaceous formations. Pleistocene and Recent deposits rest on Cretaceous rocks in many places, especially along the valleys of larger streams where post-Pliocene erosion removed the widespread mantle of Ogallala sediments.

Common macroinvertebrate fossils in Upper Cretaceous marine units of western Kansas are illustrated in Figures 3-5. Photomicrographs of representative thin sections of Cretaceous rocks are illustrated in Figure 6.

DESCRIPTIONS OF CRETACEOUS UNITS IN FIELD-TRIP AREA

Dakota Formation

Only the upper or Janssen Clay Member of the Dakota Formation is exposed along the route of the field trip. This unit is 52 feet thick in the type area in Ellsworth County. Lithology changes abruptly and complexly both vertically and laterally in this unit. Five general rock varieties include more or less evenly bedded and generally highly ferruginous

SYSTEM	SERIES	STAGE	FORMATION	MEMBER	THICKNESS (FEET)	LITHOLOGY	TOPOGRAPHIC EXPRESSION
NEOGENE	PLEISTOCENE	Recent	Alluvium		0-70	Silt, sand, gravel	Present channel and flood plain; surface of lowest terrace.
		Wisconsinan	a. Low terrace deposits		a. 0-100	Silt, sand, gravel	Low terraces lying approximately 15 to 20 feet above Smoky Hill and Saline Rivers.
			b. Bignell (Brady Soil)		b. 0-2?	Loess	Thin mantle on upland
			c. Peoria		c. 0-50	Loess	Thin mantle on upland
		Illinoisan	(Sangamon Soil) Loveland			Loess; laminated sand and silt	Thin mantle on upland grading laterally into stream-laid deposits in upper part of Kansan-Illinoisan high-terrace complex.
			Crete		0-65	Sand and gravel	Widely distributed in dissected Kansan-Illinoisan high-terrace complex.
		Kansan	Sappa		0-45	Silt and sandy silt with lenses of sand, gravel, and volcanic ash (Pearlette ash bed)	Channel deposits truncated by overlying Illinoisan deposits in high-terrace complex.
			Grand Island		0-35	Sand and gravel	Basal part of channel deposit underlying the high-terrace complex.
		Nebraskan	Holdrege		0-25	Gravel	Channel deposits lying high on valley walls or on divides between major streams in Russell and Ellis counties.
	PLIOCENE		Ogallala		0-226	Chiefly sand, with clay, silt, and gravel; in part lime-cemented to form "Mortar beds," in part cemented with silica to form "quartzite." Also contains some chert, bentonitic clay, volcanic ash, and limestone.	Loess-mantled cap rock of upland surface of High Plains. Outlying remnants cap divides in highly dissected areas. Exposed in steep bluffs and cliffs at upland margin along larger stream courses.
CRETACEOUS	GULFIAN	CAMPANIAN	Pierre Shale	Weskan Shale	170	Dark-gray shale with clay-ironstone and limestone concretions, phosphate nodules, and bentonite.	Canyons and slopes in valleys of larger streams; local badlands.
				Sharon Springs Shale	155	Dark-gray shale, organic-rich in upper part, with phosphate nodules, limestone concretions, calcareous septarian concretions, and many thin seams of bentonite.	Canyons and slopes in valleys of larger streams; commonly forms badlands.
		? CONIACIAN-SANTONIAN	Niobrara Chalk	Smoky Hill Chalk	560-620	Olive-gray shaly chalk mostly weathering grayish orange and yellowish gray; many thin seams of bentonite. Where intensely weathered lacks shaly structure and forms resistant cap rock.	Canyons and badlands along valley walls of larger streams. Many rock pinnacles.
				Fort Hays Limestone	55-75	Light-olive-gray chalky limestone, mostly weathering pale grayish orange, yellowish gray, or nearly white.	Cliffs along valley walls of large streams. Cap rock on buttes, mesas, and low bluffs.

CRETACEOUS	GULFIAN	TURONIAN	Carlile Shale	Codell Sandstone	0-31	Light-olive-gray quartzose sandstone and siltstone, commonly streaked with shale, locally calcareous.	Lower part of cliffs held up by Fort Hays Limestone Member. Locally absent or too thin to be expressed physiographically.
				Blue Hill Shale	168-185	Dark-gray shale, very silty near top, with numerous zones of calcareous concretions and one or two zones of clay-ironstone concretions.	Gullied lower slopes of Fort Hays Escarpment; slopes of buttes and mesas capped by outliers of Fort Hays Limestone Member.
				Fairport Chalk	90-118	Olive-gray laminated shaly chalk with numerous beds of chalky limestone and marly chalk, and seams of bentonite. Lower part generally weathered yellowish gray to grayish orange.	Lower part typically underlies upland plain in western part of Smoky Hills. Along larger stream courses, especially near the Fort Hays Escarpment, member forms steep slopes and precipitous cutbanks. Local badlands.
			Greenhorn Limestone	Pfeifer Shale	21	Olive-gray to olive-black shaly chalk and chalky, commonly nodular or concretionary limestone; generally weathered yellowish gray to pale grayish orange.	Steep slopes, and locally cliffs, along valleys of larger streams.
				Jetmore Chalk	20-21	Olive-gray to olive-black shaly chalk and chalky limestone, the latter commonly weathered yellowish gray to pale grayish orange.	Cliffs and steep bluffs along courses of larger streams.
				Hartland Shale	29-35	Olive-gray to olive-black shaly chalk with scattered beds of chalk and chalky limestone and several conspicuous beds of bentonite.	Upper part: steep slopes below cliffs and bluffs held up by Jetmore Chalk Member. Lower part: gentle slopes, poorly exposed.
		CENOMANIAN		Lincoln Limestone	21-25	Olive-black shaly chalk, light-olive-gray to olive-gray chalk or chalky limestone, pale-yellowish-brown skeletal limestone and numerous seams of bentonite. Basal bed commonly conglomeratic.	Upper part: gentle slopes, poorly exposed. Lower part: cutbanks and cliffs along courses of large and some small streams.
			Graneros Shale		25-36	Dark-gray shale, quartzose sandstone, skeletal limestone, with a 1-foot-thick bentonite bed near top.	Gentle grass-covered slopes. Best exposed in cutbanks along courses of larger streams.
			Dakota Formation	Janssen Clay	about 50	Dark-gray silty carbonaceous shale, quartzose sandstone and siltstone, lignite, and mudstone.	Steep grass-covered but commonly gullied slopes, low bluffs, local badlands.

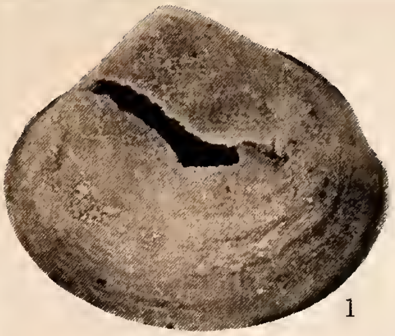
Table 1.- (Begins on opposite page.) Stratigraphic units in field-trip area.

quartzose sandstone, dark-gray, flaky-weathering shale, carbonaceous and/or sandy shale with local lignite, intensely cross-bedded, well-washed, fine- to coarse-grained sandstone, and variegated mudstone. The Dakota represents deltaic deposition along the margin of an eastwardly transgressing sea. Cross-bedded sandstone is interpreted as channel deposits; variegated mudstone represents flood-plain sediments. Carbonaceous or sandy shale and lignite are interpreted as lagoonal and marsh deposits near the seaward margin of the delta. Reed? molds may be observed *in situ* in siltstone with highly disturbed bedding beneath lignite beds at Stop 1. Gray shale at or near the top of the Dakota generally contains concretions or beds of clay-ironstone and locally contains arenaceous foraminifers suggestive of brackish water of interdistributary bays. Uppermost Dakota beds differ greatly in aspect in short distances and are commonly gradational with the Graneros, but evenly bedded sandstone that most commonly lies in this position is believed to represent shore-zone sand deposits that were redistributed during ultimate inundation of the deltaic margin by the advancing sea. Molds of marine mollusks are locally concentrated in great numbers in such beds at localities in Russell, Lincoln, and Mitchell counties. Localities in Russell and Lincoln counties contain a number of species that occur also in the Woodbine Formation of Texas (Hattin, 1965, p. 87), including *Geltena obesa* Stephenson, *Brachidontes filisculptus* var. *microcostae* Stephenson, and *Anatimya longula* Stephenson.

Graneros Shale

The nonuniform position of the Dakota-Graneros contact, as determined by reference to marker beds, reflects intertonguing of adjacent parts of the two units. Complexly varied lithology in the upper part of the Dakota gives way upward to more uniform lithology in the lower part of the Graneros Shale. In the immediate vicinity of the field-trip route, the Graneros Shale ranges from 24.9 to 36.4 feet in thickness, averaging 31.5 feet for nine complete sections in Russell, Ellsworth and Lincoln counties. The lower part of the formation consists mainly of dark-gray silty shale that is irregularly interlaminated with silt and fine sand and contains a few to several beds of thin-bedded, commonly cross-laminated, well-sorted, mostly noncalcareous quartzose sandstone. Distribution and abundance of sand, silt

Figure 3.- Common macroinvertebrate fossils of Dakota, Graneros and Greenhorn Formations. (1) *Geltena obesa* Stephenson, upper part of Dakota Formation, X2; (2) *Brachidontes filisculptus* var. *microcostae* Stephenson, upper part of Dakota Formation, X2; (3) *Watinoceras reesidei* Warren, Jetmore Chalk Member of Greenhorn, X2; (4) (9) *Ostrea beloiti* Logan, upper part of Graneros Shale, 4 is X2, 9 is X1 1/3 (also occurs in lower part of Lincoln Limestone Member of Greenhorn); (5) *Callistina lamarensis* (Shumard), lower part of Graneros, X2 2/3; (6) *Exogyra columbella* Meek, lower part of Graneros, X2; (7) *Inoceramus pictus* Sowerby, Hartland Shale Member of Greenhorn, X1½ (also occurs in Lincoln Limestone Member); (8) *Plesiacanthoceras amphibolum* (Morrow), upper part of Graneros, X1, (10) *Inoceramus labiatus* (Schlotheim), Jetmore Chalk Member of Greenhorn, X2/3 (also occurs in Pfeifer Shale Member of Greenhorn and lowermost part of Fairport Chalk Member of Carlile).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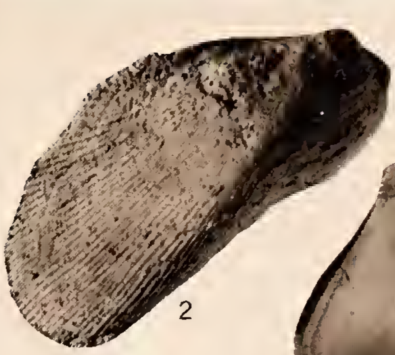
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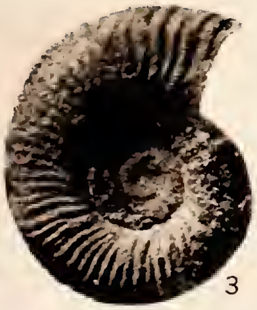
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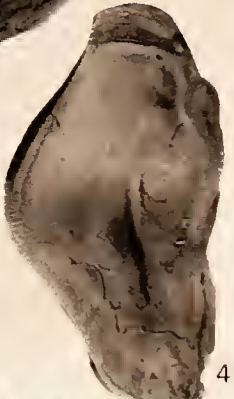
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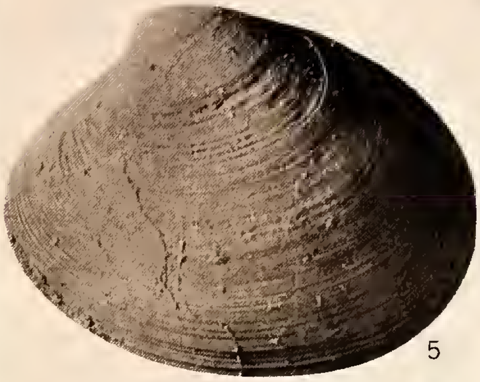
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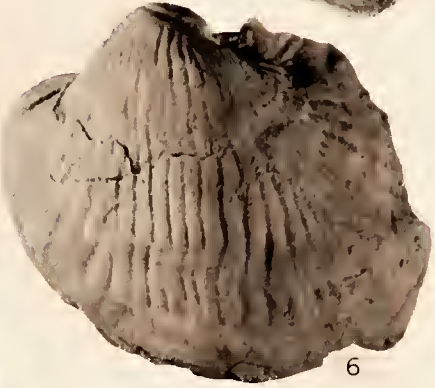
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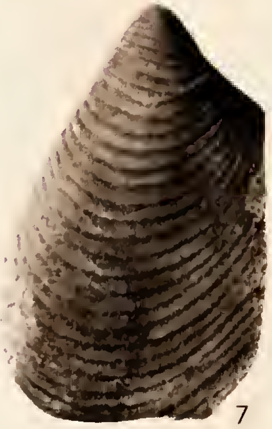
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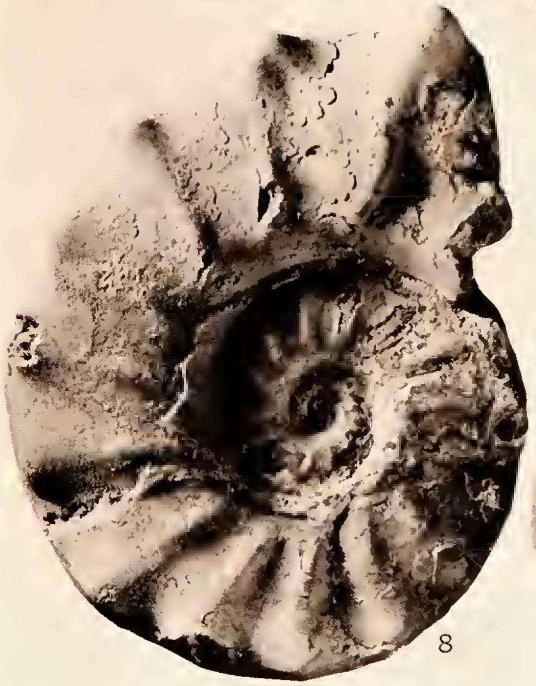
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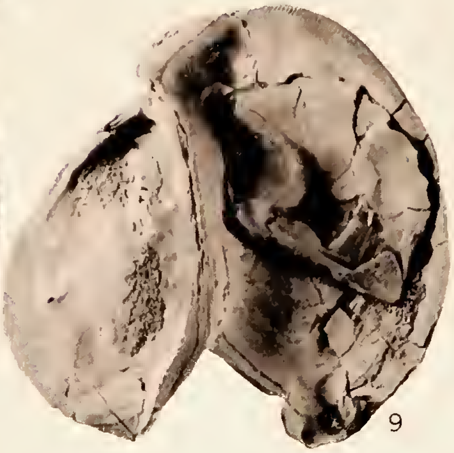
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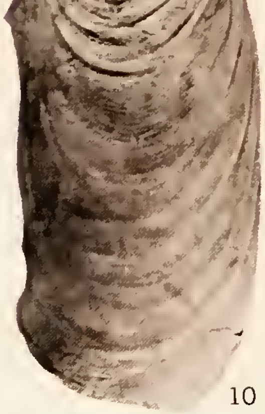
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and carbonaceous debris suggest deposition on the foreset slope of the deltaic complex mentioned above. Near-absence of calcareous beds, absence of ammonites, dominance of arenaceous foraminifers, rarity of planktonic foraminifers, and occurrence of Lingula in the lower part of the Graneros Shale all suggest brackish water that probably resulted from river discharge. The most common macroinvertebrates in this part of the formation are Callistina lamarensis (Shumard) and Exogyra columbella Meek and the strata have been assigned to the Callistina lamarensis Assemblage Zone by Hattin (1965, in press).

The upper part of the Graneros comprises dark-gray silty shale that commonly includes a few to several thin beds of calcareous sandstone in the lower part and thin beds of skeletal limestone in the upper part. The shale is weakly calcareous locally. Ripple marks and cross-laminations are common features of the calcareous sandstone beds. Upward increase in number of foraminifers and appearance of ammonites in the upper part of the Graneros and the general increase in calcium carbonate content of the rocks suggest that salinity increased progressively as Graneros deposition proceeded. Carbonaceous matter and quartzose sand and silt are generally less abundant than in the lower part of the formation, suggesting decreased deltaic influence during deposition of the upper part of the Graneros. These beds are broadly analogous to bottomset beds of modern deltas. Chief macroinvertebrates in upper Graneros strata are Ostrea beloiti Logan, Plesiacanthoceras amphibolum (Morrow), Inoceramus rutherfordi Warren, and Borissiakoceras reesidei Morrow. Dominance of the first of these has prompted me (Hattin, 1965, in press) to assign these beds to the O. beloiti Assemblage Zone.

Greenhorn Limestone

Lincoln Limestone Member.- Basal beds of the Lincoln Limestone Member consist generally of cross-bedded and cross-laminated skeletal, and locally conglomeratic, limestone that lies with sharp stratigraphic contact and abrupt lithologic contrast upon beds of the Ostrea beloiti Assemblage Zone across much of Kansas but on the older beds of the Callistina lamarensis Assemblage Zone at the southern end of the central Kansas outcrop. Nondeposition and local erosion of the upper part of the Graneros were followed by renewed deposition in a shallow-water zone of considerable turbulence that gave rise to these relatively coarse-grained skeletal rocks. Ostrea beloiti is locally concentrated in great numbers in these beds, and Exogyra columbella, possibly reworked from the lower part of the Graneros, occurs rarely in basal Lincoln beds. Molds of a large ammonite, probably Dunveganoceras pondi Haas, are common locally in the basal Greenhorn, and these beds mark the oldest occurrence in Kansas of Inoceramus pictus Sowerby, which locally is host to a small Exogyra that is characterized by a broad attachment surface. Initial turbulence during early Greenhorn deposition gave way to quieter conditions far from the eastern shoreline, and beds of laminated, olive-black chalk accumulated under conditions generally unfavorable to bottom-dwelling forms. Scattered flattened valves of *I. pictus* and a few molds of a small ammonite, possibly *Eucalyococeras*, and, in one locality, excellently preserved pedunculate cirripeds of the genus *Stramentum*, comprise nearly the entire fauna in the middle part of the Lincoln. Over much of central Kansas, Lincoln deposition terminated with accumulation of a zone of skeletal limestone lenses composed chiefly of remains of *Inoceramus* and probably representing a brief return to depths shallow enough to permit occasional reworking of bottom deposits by wave action. Concentration of debris originally scattered widely through the sediment resulted from this renewed turbulence.

Hartland Shale Member.- The term shale, in the usual sense of fissile clayey rock, is inappropriate for the Hartland which consists dominantly of laminated olive-black chalk with scattered beds of lighter colored chalky limestone as much as 0.9 foot thick and a few beds of bentonite. Some of the chalky limestone beds are demonstrably time parallel because they maintain a uniform relationship to marker bentonites. The member is 29 to 32 feet thick in the immediate vicinity of the field trip. During Hartland deposition environmental conditions were generally inhospitable to benthonic forms of life, possibly owing to the smothering effect of fine-grained sediment, or to poor circulation, or to both of these factors. The chalky limestone beds are believed to have resulted either from periods of better circulation, perhaps during storms, or from periods of slower sedimentation. Such beds are generally more richly fossiliferous than the intervening chalk units and commonly contain numerous burrow structures.

Inoceramus pictus dominated the sea floor through much of Hartland deposition, although *Inoceramus labiatus* (Schlotheim) characterizes the uppermost part of the member. A limestone bed lying near the middle of the member contains *Cerithiopsis* sp. and *Pteria* sp. Otherwise, the Hartland macroinvertebrate fauna consists entirely of cephalopods including *Kanabiceras kanabense* (Stanton) (sparse), baculitids [including a few specimens identified as *Sciponoceras gracile* (Shumard)], *Worthoceras vermiculum* (Shumard) (sparse), *Allocrioceras pariense* (White), and *Metoicoceras whitei* Hyatt.

Jetmore Chalk Member.- The Jetmore Chalk is 20 to 21 feet thick in the field-trip area and is similar lithologically to the Hartland but contains more numerous, more closely spaced, mostly thicker and more prominent beds of chalky limestone. The chalky limestone beds are dark olive gray where fresh but commonly are weathered to some shade of orange. The chalky limestone beds appear to be time parallel because of uniform position with respect to marker bentonites and appear to have originated in essentially the same manner as those in the Hartland. As in the Hartland, the limestone beds are generally more fossiliferous than the intervening shaly chalk beds. The conspicuously burrowed character of nearly all of these limestones suggests periods of better circulation which favored development of the extensive mobile infauna that produced the numerous burrow structures. The upper half of the member contains a profusion of *Inoceramus labiatus* valves which seemingly reflect optimum conditions for growth of the species during deposition of that part of the Jetmore. Numerous lenses of hard skeletal limestone in these upper beds indicate occasional stirring of bottom sediments by currents or waves. During this time interval, generally better circulation and perhaps also a slower rate of sedimentation aided the establishment of a limited epifauna including *Ostrea*, rare cirripeds and very rare *Discinisca*. Of course, the barnacles may have been attached to floating debris, but *Ostrea* is attached to valves of *I. labiatus*. Other known fossils in the Jetmore are cephalopods including *Watinoceras reesidei* (common), *Baculites* cf. *B. besairiei* (sparse), *Mammites* (rare), and *Tragodesmoceras bassi* (sparse).

Pfeifer Shale Member.- The Pfeifer consists chiefly of laminated chalk and chalky limestone but differs from the Jetmore in having numerous irregular beds and concretions of chalky limestone as well as more or less even layers of such rocks. The layers of limestone are believed to be essentially time parallel because of uniform position with respect to bentonite marker beds. This member is approximately 21 feet thick in the field-trip area. Depositional conditions that prevailed during the latter half of Jetmore time continued little changed during accumulation of the Pfeifer. Shaly chalk in the lower two-thirds of the member contains a profusion of *Inoceramus* valves. Abundance of shell debris in chalky limestones in this part of the Pfeifer suggests that such beds may have originated during wave or current stirring of carbonate mud on the sea floor.

Concretions of chalky limestone contain fewer fossils than the other limestone beds and formed by cementation of carbonate mud around one or more shells that usually were whole, or around other fossils. Early diagenetic origin is demonstrated by preservation "in the round" of contained fossils and bending of adjacent chalk layers around the concretions as a result of compaction.

Inoceramus labiatus dominates the Pfeifer macroinvertebrate assemblage and *Inoceramus cuvieri* Sowerby makes its first appearance in the upper part of the member. *Ostrea* is a common epizoan on *Inoceramus* shells, and barnacles are attached sparingly to valves of *I. cuvieri*. Other Pfeifer fossils include *Collignoniceras woollgari* (Mantell) which is found in the upper few feet of the member, *Teredo*-like borings in petrified wood, *Watinoceras* (sparse), juvenile hamitid? cephalopods, and a smooth species of *Baculites*. In addition, Morrow (1941) has reported *Mammites* in the Pfeifer Member.

Carlile Shale

Fairport Chalk Member.- Although the Fairport Chalk Member has been classified historically as a member of the Carlile, the unit is genetically related, both faunally and lithologically, to the Greenhorn Limestone. Furthermore, the lowermost part of the Fairport is indistinguishable from the Pfeifer Shale Member of the Greenhorn, suggesting need for upward shift of the existing Pfeifer-Fairport boundary. Additionally, the Fairport fulfills all qualifications for formational status and is, therefore, inappropriately ranked as a member (Hattin, 1962, p. 20). The Fairport ranges from 90 to 118 feet in thickness in the area of this field trip.

The Fairport consists chiefly of olive-gray to dark-olive-gray chalk with beds of chalky limestone in the lower part and beds of marly chalk in the upper part. Lenses of skeletal limestone are scattered throughout the middle and upper parts. Terrigenous detritus constitutes as little as 15 percent of the shaly chalk, increasing to as much as 50 percent of the rock in the uppermost part of the member. As in the Greenhorn Limestone, many of the widespread layers of chalky limestone and marly chalk of the Fairport have a uniform relationship to marker bentonites across the west-central Kansas outcrop and are thus believed to be essentially time parallel. Occasional but widespread wave agitation of lime mud on the sea floor has been suggested by Hattin (1962, p. 102) as a mechanism underlying the production of widespread limestone beds. Stronger wave or current action produced lag concentrates of skeletal debris that are now skeletal limestone lenses in the middle and upper parts of the formation. Shaly chalk beds containing remains of few benthonic organisms other than Inoceramus probably represent deposition in quiet, poorly circulated water.

Macroinvertebrate fossils in Fairport rocks are little more diversified than in the Greenhorn Limestone, which is of similar thickness and lithology. A largely undescribed group of epizoans occurs widely in the Fairport and is best developed in parts of the section containing skeletal limestone. These fossils, attached to Inoceramus or to one another, include Serpula tenuicarinata Meek and Hayden, Membranipora sp., Proboscina n. sp., Ostrea congesta, Stramentum n. sp., and Exogyra sp. (rare). The extensive development of this epifauna in those parts of the section containing skeletal limestone lenses reflects in part the better circulation of bottom waters during formation of the lenses. Slower sedimentation rate is suggested by occurrence of several generations of epizoans on Inoceramus in some localities.

Fairport cephalopods include Scaphites patulus Cobban, Actinocamax manitobensis (Whiteaves) (rare), and Collignoniceras woollgari (Mantell). Inoceramus labiatus (broad form) occurs in the lowest part of the Fairport and grades upward into I. latus Sowerby which occurs throughout the remainder of the member. A new species of sulcate inoceramid resembling I. latus occurs near the top of the Fairport.

Abundance of cephalopods, planktonic foraminifers, and carbonate rocks suggests that waters were of normal salinity during deposition of the Greenhorn and Fairport sediments.

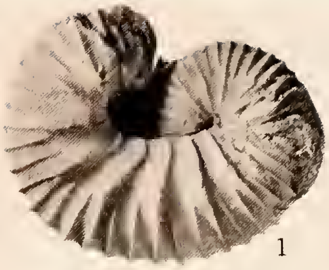
Blue Hill Shale Member.- The Blue Hill Shale Member ranges in thickness from 168 to 185 feet in the field-trip area. The member consists chiefly of dark-gray silty shale that weathers flaky and is sandy near the top. Zones of septarian concretions characterize most of the member and clay-ironstone concretions occur in two zones in the lower half of the unit. Fine-grained noncalcareous sediment in the Blue Hill represents influx of terrigenous detritus associated with the regression that is first reflected in the increase in land-derived sediment in the upper part of the Fairport. Pelagic and benthonic faunal elements indicate water of normal or nearly normal salinity but the sparse benthos suggests turbid water and soft mud bottom that was largely inhospitable to bottom-dwelling forms.

Rare small-scale oscillation ripple marks and gentle cross-laminations in siltstone, and local fish-tooth conglomerate, all in the upper part of the member, manifest shallower water during deposition of that part of the member.

Blue Hill macroinvertebrates that range upward from the Fairport include *Inoceramus cuvieri*, *I. latus*, and *Ostrea congesta*. Of these, only *Inoceramus latus* ranges higher than the middle part of the Blue Hill. The bottom fauna also includes *Inoceramus flaccidus* White, *Lucina juvenis* Stanton, two species of *Yoldia*, five species of gastropods, a crab, and a lobster. Ammonites include *Collignoniceras hyatti* (Stanton), *Proplacenticeras pseudoplacenta* (Hyatt), *Scaphites carlilensis* Morrow, and *Binneyites aplatus* (Morrow) (rare). Forms ranging virtually throughout the Blue Hill and therefore characteristic of the member include *C. hyatti* and *S. carlilensis*.

Codell Sandstone Member.- In the field-trip area the Codell ranges from 5.7 to 31 feet but over much of northern Kansas is less than 1 foot thick and is not recognized locally in the southern part of the west-central Kansas outcrop. The member is gradational vertically and laterally with upper beds of the Blue Hill. The Codell consists mostly of well-sorted fine quartzose sand and coarse quartzose silt and contains small quantities of feldspar and a limited suite of stable heavy minerals. Silty shale occurs in the Codell in some sections, including that at Stop 10. The unit is only locally cross-bedded but is extensively burrowed in some places. Fossils are poorly preserved and rare in west-central Kansas, consisting of a few shark teeth, clam molds and a small foraminiferal assemblage dominated by arenaceous species. Codell sediments indicate approach to the central Kansas area of the eastern shoreline of the Western Interior Sea which was regressing during deposition of the Carlile Shale.

Figure 4.- Common macroinvertebrate fossils in Carlile and Niobrara Formations. (1) *Scaphites carlilensis* Morrow, Blue Hill Shale Member of Carlile, X1; (2) *Ostrea congesta* Conrad, Smoky Hill Chalk Member of Niobrara, X1 (similar forms occur in Jetmore Chalk Member and Pfeifer Shale Member of Greenhorn, Fairport Chalk Member and Blue Hill Shale Member of Carlile, and Fort Hays Limestone Member of Niobrara); (3) *Collignoniceras woollgari* (Mantell), Fairport Chalk Member of Carlile, X1; (4) *Collignoniceras hyatti* (Stanton), Blue Hill Shale Member of Carlile, X2/3; (5) *Inoceramus latus* Sowerby (juvenile), Fairport Chalk Member of Carlile, X2 (also occurs in Blue Hill Shale Member of Carlile); (6) *Inoceramus cuvieri* Sowerby, Fairport Chalk Member of Carlile, X1 (also occurs in Pfeifer Shale Member of Greenhorn and possibly in lower part of Blue Hill Shale Member of Carlile); (7) *Inoceramus flaccidus* White, Blue Hill Shale Member of Carlile, X1.



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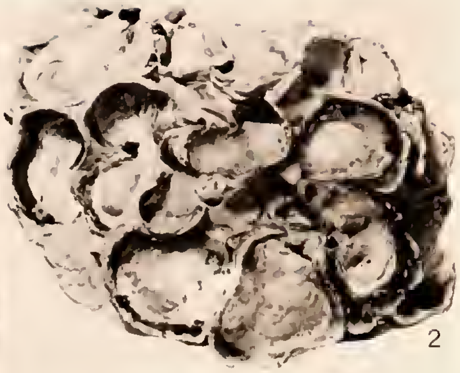

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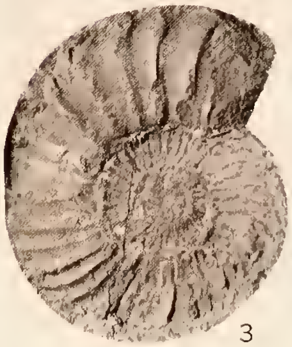

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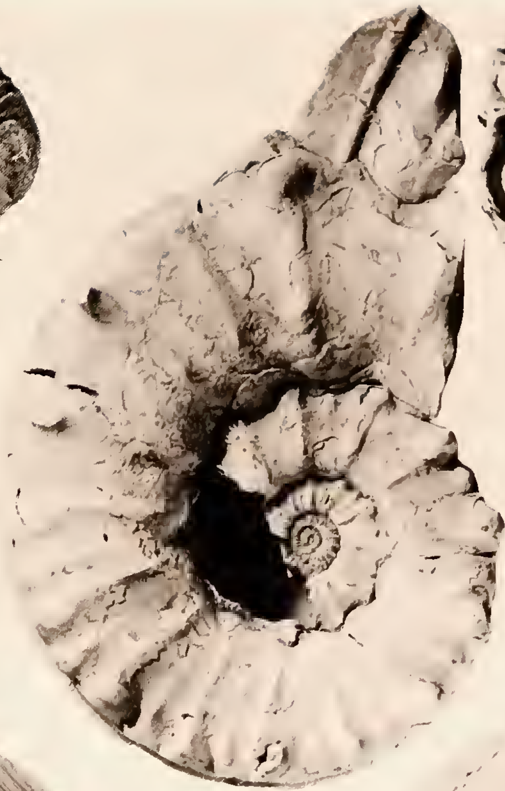

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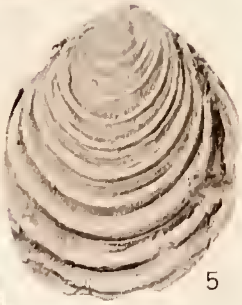

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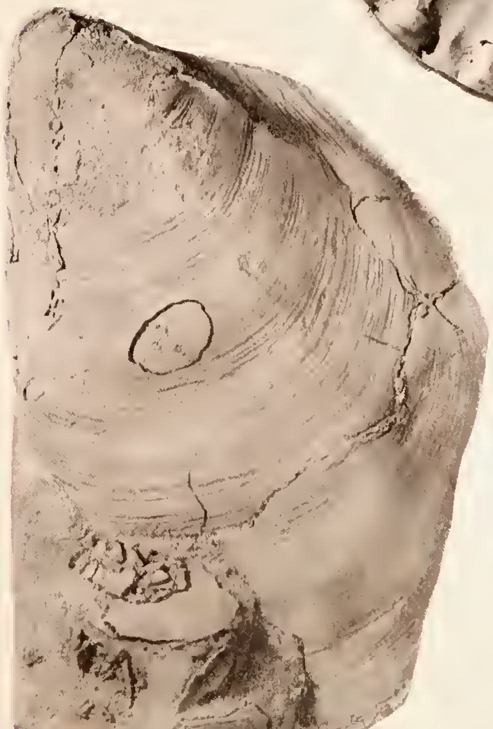

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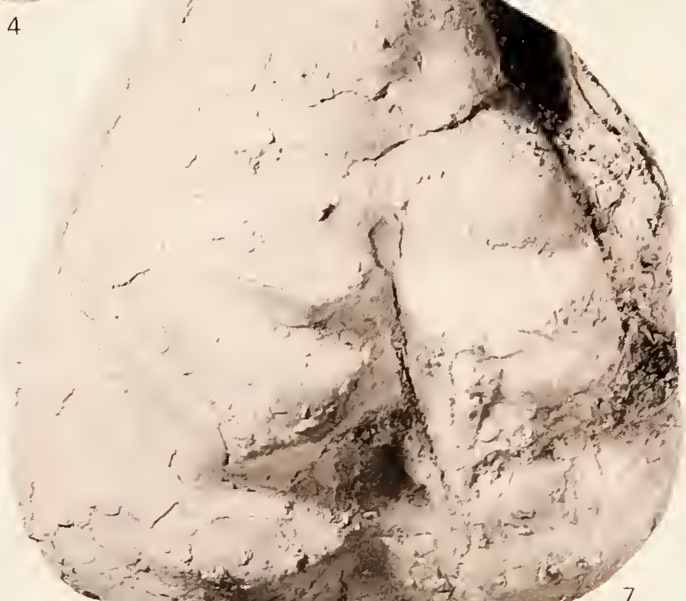

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Niobrara Chalk

Fort Hays Limestone Member.- The Fort Hays Limestone Member is 55 to 75 feet thick in the field-trip area, the latter figure being near the maximum for the west-central Kansas outcrop. The unit is characterized by thick to very thick beds of relatively resistant chalky limestone that is light gray to medium gray or light olive gray where fresh but more commonly weathered yellowish gray, grayish or pale grayish orange, or nearly white. The rock is mostly homogeneous micrograined carbonate rock composed largely of microspar, foraminifers, and calcareous nannoplankton remains, but with locally abundant Inoceramus prisms and shell fragments of Inoceramus and Ostrea. Except for the basal beds, the rock is composed of 88 to 98 percent calcium carbonate (Runnels and Dubins, 1949, p. 17). The Fort Hays is conspicuously marked in many beds by irregular-shaped burrow structures that were completely backfilled with cuplike increments of chalky sediment. Such structures are most evident in little-weathered rock or on solution-etched surfaces. Slender cylindrical burrow structures, filled with pyrite, limonite, or visibly crystalline calcite, are common in the upper half of the member at Stop 9. Large burrows crisscrossed by grooves made by clawlike appendages of arthropods have been collected from the Fort Hays at several localities. One bed at localities 9 and 10 is in part thinly laminated to gently cross-laminated.

Except for the several kinds of burrow structures, remains of benthonic macroinvertebrates in the Fort Hays are of drastically limited diversity, consisting primarily of Inoceramus deformis Meek and Ostrea congesta Conrad, the latter usually encrusting the former. Because isolated bowl-like valves of Inoceramus deformis are generally oriented concave upward, the attached specimens of Ostrea are preserved "facing" downward. Articulated valves of Inoceramus deformis are not commonly preserved in the articulated position. The only other common macroinvertebrate fossil in the Fort Hays is a species of Serpula.

The Fort Hays Limestone Member lies upon the Codell Sandstone Member of the Carlile Shale with regional unconformity. In Colorado, several fossil zones lie between Carlile beds containing Collignoniceras hyatti (the youngest Carlile zone recognized in west-central Kansas) and Fort Hays beds containing Inoceramus deformis. Because of the gradational nature of Blue Hill and Codell strata and limited development of the Codell across much of central Kansas, the poorly fossiliferous Codell is not believed to represent all of the missing zones in west-central Kansas. The missing strata, if ever deposited, were removed before Niobrara deposition, but there is little relief and no unequivocal evidence for subaerial erosion at the unconformity. Apparently the sea floor lay above wave base for an extended interval of time following westward regression, which is reflected in sediments of the Carlile Shale. The writer (Hattin, 1962, p. 124) has postulated renewed transgression along the distant eastern margin of the Western Interior Sea while the west-central Kansas area remained above wave base. By the time deposition of the Niobrara began, the central Kansas region was far beyond the reach of terrigenous detritus being carried to the sea from the east or northeast.

Chalky limestone beds of the Fort Hays, like those in the Greenhorn, are believed to reflect deposition in well-circulated water with concommitant agitation of fine carbonate mud at relatively shallow depths. Disarticulated, overturned, and fragmentary shells of *Inoceramus deformis*, broken and disarticulated shells of *Ostrea congesta*, and local cross-laminations attest the mechanical disturbance of Fort Hays sediment. Ubiquitous and locally profuse burrow structures indicate a possible mechanism for the homogenization of Fort Hays sediment, and manifest an extensive infauna not represented in the bottom fauna during later deposition of the Smoky Hill Chalk Member.

Smoky Hill Chalk Member.- The Smoky Hill Chalk Member ranges approximately from 560 to 620 feet in thickness along the Smoky Hill River in the field-trip area. The unit is dominated by light-olive-gray to olive-gray shaly chalk that is speckled by nearly white spheroidal calcareous pellets. The chalk is commonly weathered grayish orange to pale grayish orange, or dark yellowish orange to very pale yellowish orange, or yellowish gray. The rock apparently loses prominent bedding features and becomes harder and more massive during intense weathering. Such hard rock caps pinnacles and cliffs in many areas of badlands developed in the Smoky Hill Chalk Member. Bentonite seams are prominent features of the member and can be used, in groups, to effect regional correlation (V.B. Cole, oral communication).

During Smoky Hill deposition the sea floor was apparently deeper, and the water quieter and less well circulated than during Fort Hays deposition. Burrow structures, so common in the Fort Hays, are virtually absent in the Smoky Hill, probably because the oxygen supply was insufficient for a highly mobile infauna. In addition, the immense size of *Inoceramus* in the Smoky Hill may reflect extraordinary development of respiratory tissue in response to poorly oxygenated water*. Similar huge specimens of *Inoceramus* are known in rock of the same lithology in the Greenhorn and Fairport. The lower part of the member is characterized by *Inoceramus grandis* (Conrad) and *Inoceramus platinus* Logan ranges through most of the member. The only other common benthonic macroinvertebrate in these rocks is *Ostrea congesta*, and in much of the section even these are rare. Specimens of *Stramentum* and *Serpula* are rare elements of the benthonic macroinvertebrate fauna. *Ostrea* is found most commonly encrusting one or both valves of *Inoceramus*. The latter must have been recumbent during life because (1) none occur erect in the sediments, (2) there was no suitable substratum to which the large shells could have been attached, and (3) growth form of attached oysters suggests a recumbent position for *Inoceramus*. Occurrence of *Ostrea* on both valves of many *Inoceramus* specimens proves that some of the inoceramids were overturned, apparently during life, possibly by fish or by occasional storm activity, or maybe even by the clam itself. Despite seemingly low oxygen content of the water, the probability of overturning by fish cannot be discounted, especially in light of the abundance of shell-crushing shark teeth that have been collected in the Niobrara. Fragments of *Inoceramus* and *Ostrea* and disarticulated valves of *Inoceramus* are common in these rocks and may be evidence of predation by such fish.

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*However, large species of *Inoceramus* are characteristic in rocks of this age elsewhere in the Northern Hemisphere, and some large specimens are known in rocks representing a closer-to-shore environment than that in which the Smoky Hill beds were deposited (W.A. Cobban, written communication, 1965).

Other macroinvertebrates in the Niobrara fauna include baculitids, Clioscaphites choteauensis Cobban, certain rare ammonites, cuttlefish, belemnitids, and free-swimming crinoids, all of which were probably inhabitants of more freely circulating, better oxygenated surface waters. Crinoids, cephalopods, and planktonic foraminifers all suggest fully marine conditions during Smoky Hill deposition.

Deposition of Smoky Hill sediments was relatively rapid, at least in some parts of the section. Tall cone-shaped ecovariants of Ostrea congesta, found in the same beds with the encrusting form, apparently were attached to small shell fragments. The growth form is assumed to reflect the rapid upward growth that was necessary to prevent burial. Oysters observed on baculitids in two horizons are all small, suggesting that burial occurred not long after attachment. Inoceramus shells encrusted by large numbers of oyster spat are presumed to have been dead at or soon after the time of epizoal attachment and were buried before the oysters grew very large. In contrast, Inoceramus shells heavily encrusted by thick-shelled adult oysters were alive during oyster growth, and remained unburied for lengthy periods. On such Inoceramus valves, second-generation oysters are commonly attached to the shells of the earlier oyster generation.

The end of a fascinating chapter in Cretaceous history came with the major influx of terrigenous detritus into the western Kansas area at the beginning of Pierre deposition. This sediment heralded the second major Late Cretaceous regression of the Western Interior Sea in Kansas.

Pierre Shale*

The Pierre Shale is present in only a few counties in western Kansas where its total thickness is about 1,400 feet. The formation is largely dark-gray to medium-gray shale that contains gray- to brown-weathering limestone concretions, rusty- to dusky-red-weathering ironstone concretions, and thin layers of white or gray bentonite. Elias (1931) described in detail the outcrops in Wallace County where the lower one-half or less of the Pierre Shale is present. This part of the Pierre was divided by Elias into the following members, from oldest to youngest: Sharon Springs (155 ft.), Weskan (170 ft.), Lake Creek (200 ft.), and Salt Grass (60 ft.).

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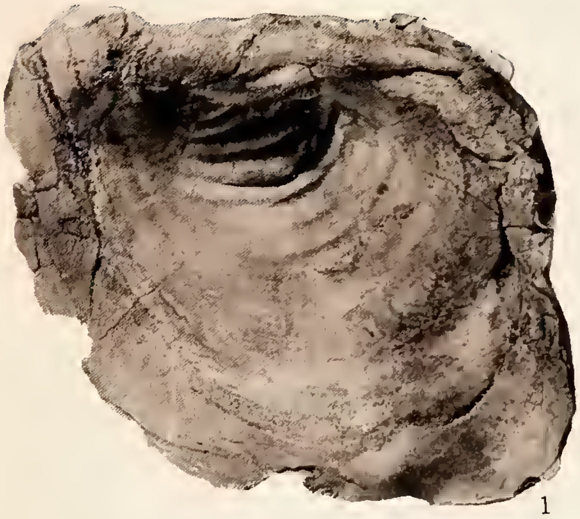
*Section on Pierre Shale prepared by W. A. Cobban

Figure 5.- Common macroinvertebrate fossils in Niobrara Chalk and Pierre Shale. (1) Inoceramus grandis (Conrad), Smoky Hill Chalk Member of Niobrara, X2/3; (2) Inoceramus deformis Meek, Fort Hays Limestone Member of Niobrara, X2/3; (3) Inoceramus platinus Logan, Smoky Hill Chalk Member of Niobrara, actual size is 35 x 34 inches; (4) (5) Baculites asperiformis Meek, Sharon Springs Shale Member of Pierre Shale, both X2/3.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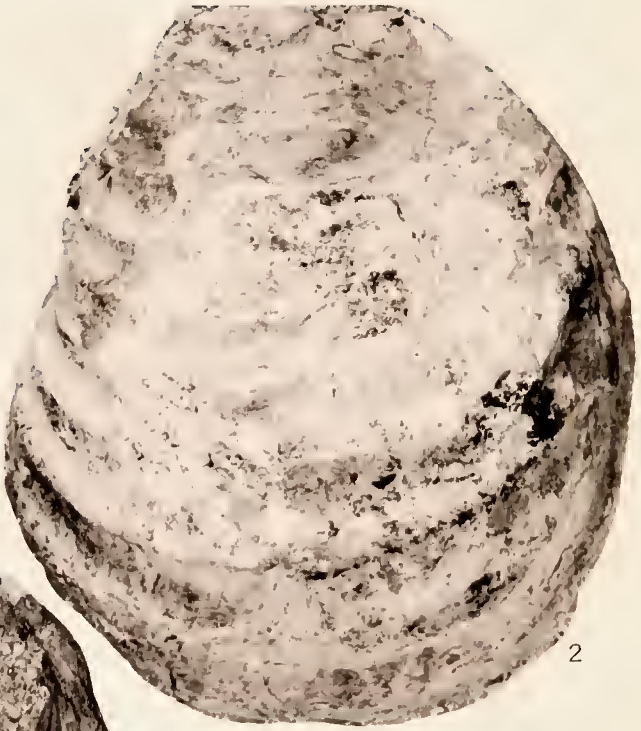
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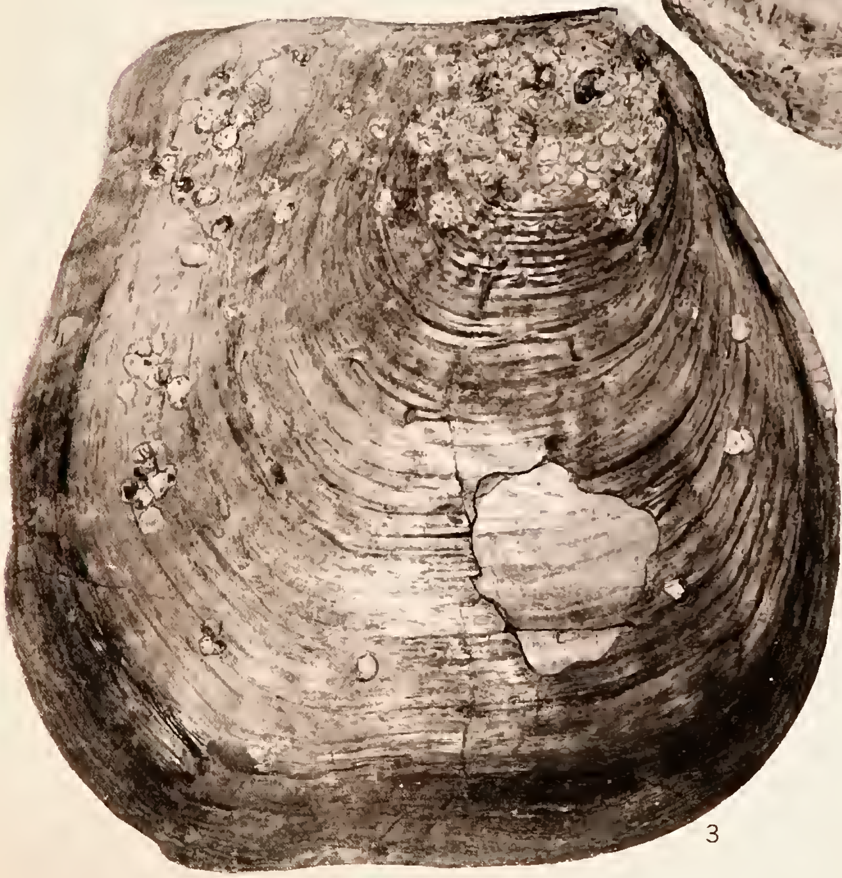
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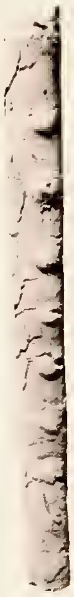
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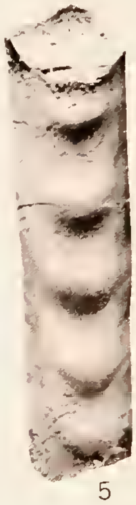
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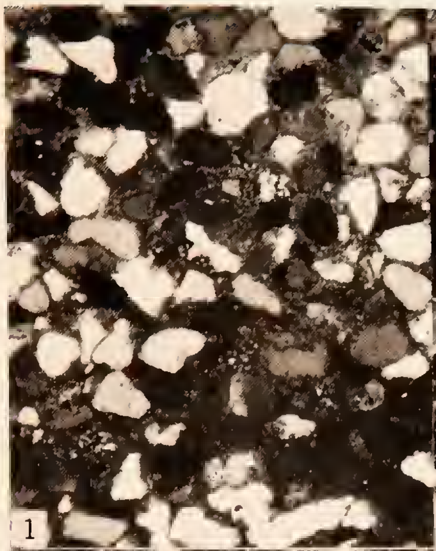
Sharon Springs Shale Member.- The Sharon Springs Shale Member, the type section of which is at McAllaster Buttes, Stop 6, consists of a poorly exposed soft lower part and a well-exposed hard upper part. The lower part, which forms half or more of the member, is a dark-gray soft shale that contains ferruginous concretionary beds and a few thin layers of bentonite. Fossils are scarce; a few of the concretionary beds contain Baculites obtusus Meek and species of Inoceramus and Pteria. This part of the Sharon Springs will not be seen on this excursion. The upper part of the member, which crops out extensively at McAllaster Buttes, is a resistant, organic-rich, buttress-forming brownish-gray shale that contains hard limestone concretions, soft phosphatic concretions, and thin layers of bentonite. A bed of very large, closely spaced septarian limestone concretions is present in the upper part; these concretions contain thick veins of pale-brown calcite in which occur a few crystals of barite. Occurrences of fossils are rare in the upper part of the Sharon Springs although one concretion contained numerous Baculites asperiformis Meek.

Weskan Shale Member.- The Weskan Shale Member consists of soft clayey shale that has numerous concretions and many beds of bentonite, some of which are ½ to 1 foot thick. The lower part contains thin ferruginous concretionary layers and small worm-burrowed phosphatic nodules. The upper part is characterized by many beds of light-gray, hard dense limestone concretions. Well-bedded lengthy limestone concretions mark the base of the member. Fossils found in the limestone concretions of the Weskan consist chiefly of species of Inoceramus, Pteria, and Anomia, and fragments of ammonites. Only the basal part of the Weskan can be seen at the McAllaster Buttes.

Lake Creek Shale Member.- The Lake Creek Shale Member is a dark-gray flaky shale that has many thin concretionary ferruginous layers that impart a rusty appearance to the outcrops. Baculitids, chiefly B. reesidei Elias, are common but other fossils are scarce.

Figure 6.- Photomicrographs of representative thin sections of Upper Cretaceous rocks of western Kansas. (1) Jarosite-cemented quartzose silty sandstone from near middle of Graneros Shale, southwestern Russell County. Crossed nicols, X75. (2) Skeletal limestone from near top of Graneros, central Russell County, showing dominance of Inoceramus prisms. Crossed nicols, X75. (3) Shaly chalk from lower part of Jetmore Chalk Member, Greenhorn Limestone, Stop 2, showing ellipsoidal pellet (near center of photograph), streaks of organic matter, and foraminifers. (4) Chalky limestone from middle part of Jetmore, Stop 2, showing foraminifers in matrix of microsparite. Plain light, X60. (5) Marly chalk from middle part of Fairport Chalk Member, Carlile Shale, southwestern Ellis County, showing spar-filled foraminifers and compressed pellets (gray ovoid bodies near center of photograph). Plane-polarized light, X150. (6) Shaly chalk from uppermost part of Fairport, showing compressed pellets (medium-gray bodies) and streaks of clay and pyrite. Plane-polarized light, X150. (7) Quartzose silty sandstone from middle part of Codell, Stop 5. Crossed nicols, X60. (8) Chalky limestone from middle part of Fort Hays Limestone Member, Niobrara Chalk, Stop 9. Plain light, X60. Compare with photograph number 4. (9) Concretionary limestone from basal part of Weskan Shale Member, Pierre Shale, Stop 6, showing foraminifers, fish bone, and pyrite (black) in matrix of microsparite. Plain light, X60.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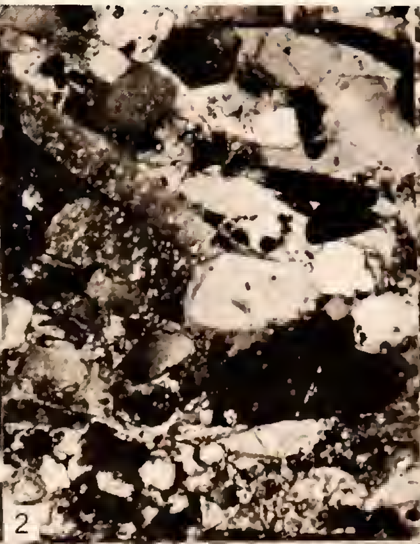
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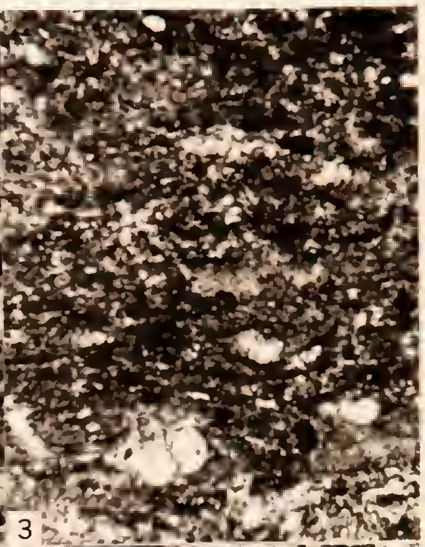
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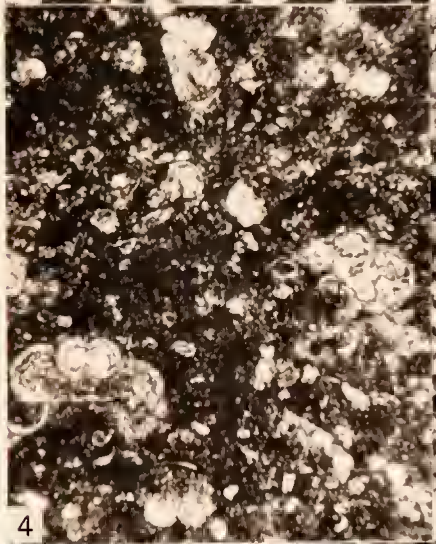
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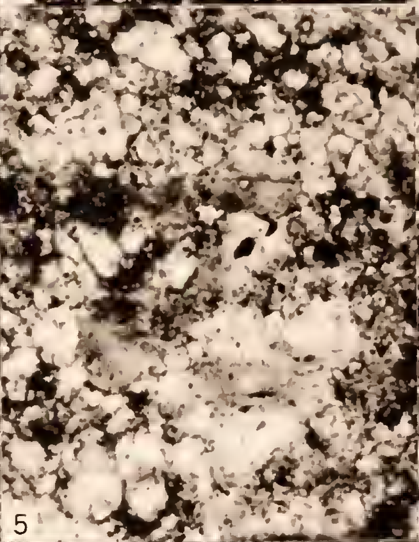
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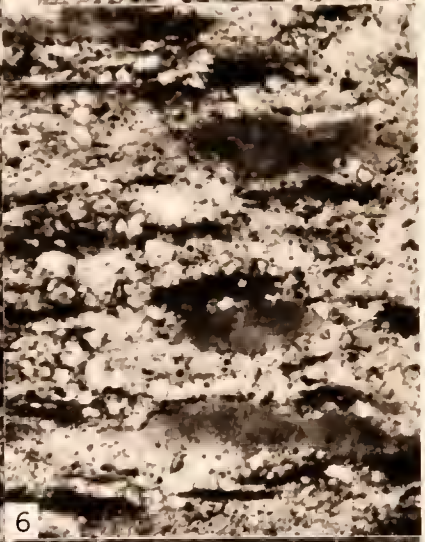
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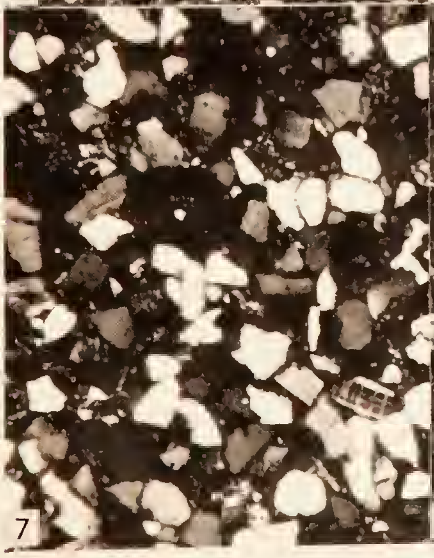
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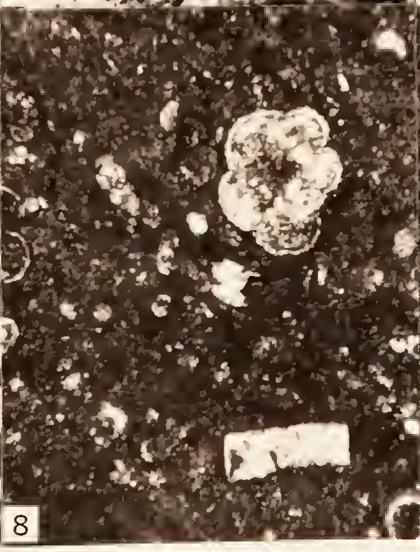
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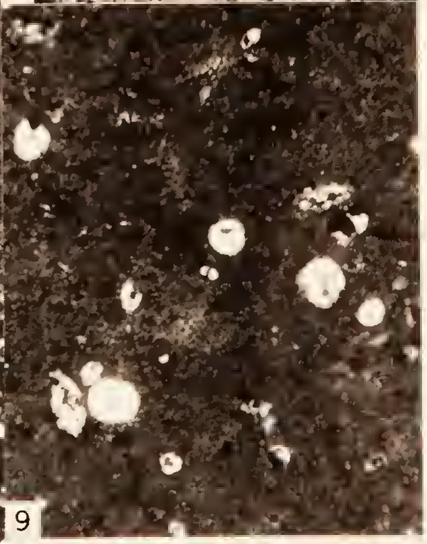
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Salt Grass Shale Member.- The Salt Grass Shale Member is a clayey shale containing limestone concretions, thin ferruginous concretions, and a few thin layers of bentonite. The most abundant fossil is Baculites eliasi Cobban.

The Pierre Shale in western Kansas was formed several hundred miles from the western shore of the Upper Cretaceous seaway and an unknown distance from the eastern shore. The formation is thin in contrast to the much thicker time-equivalent strata farther west in central Colorado. Deposition was probably very slow in Kansas during much of Pierre time, which may account for the abundance of phosphatic concretions and the paucity of fossils in much of the rocks. The fossiliferous limestone concretions in parts of the Weskan suggest that at times bottom conditions were more favorable.

LATE CRETACEOUS CYCLIC SEDIMENTATION IN WESTERN KANSAS

Formations in the upper part of the Dakota Formation and lower part of the Colorado Group record deposition during the first Late Cretaceous marine sedimentation cycle in Kansas. The stratigraphic succession is an asymmetrical cyclothem comprising seven phases including, in ascending order: (1) carbonaceous and commonly clayey siltstone and sandstone and generally silty and carbonaceous gray shale represented by the uppermost part of the Dakota Formation; (2) gray, noncalcareous silty or sandy shale with sandstone beds, represented by the lower part of the Graneros Shale; (3) gray, mostly noncalcareous silty shale with beds of calcareous sandstone and skeletal limestone and local septarian concretions represented by the upper part of the Graneros Shale; (4) shaly chalk and chalky limestone containing relatively little terrigenous detritus, represented by the Greenhorn Limestone and the Fairport Chalk Member of the Carlile Shale; (5) gray, noncalcareous silty shale with septarian concretions, represented by most of the Blue Hill Shale Member of the Carlile Shale; (6) gray, locally concretionary noncalcareous silty or sandy shale with thin sandstone beds, represented by the uppermost part of the Blue Hill Shale Member; and (7) siltstone and sandstone, commonly argillaceous, represented by the Codell Sandstone Member of the Carlile. Macroinvertebrate fossils are abundant only in phases (3) through (5).

Lithology, sedimentary structures, and fossils in these beds suggest successive changes from nearshore, shallow, brackish-water deposition in phases (1) and (2) to far offshore deposition in deeper waters of normal salinity in phase (4) and return to nearer shore, shallower water deposition through phases (5) to (7).

Cretaceous rock units above the Carlile Shale in western Kansas represent parts of a second major cycle of sedimentation in the eastern portion of the Western Interior Sea. Niobrara strata represent two subphases of maximum transgression analogous to phase (4) of the first cyclothem.

The Pierre Shale, as developed in western Kansas, represents an extended period of regressive-type sedimentation that apparently proceeded, more or less uninterrupted, for the duration of Pierre deposition.* Pierre rocks of Kansas are analogous to phase (5) of the first cyclothem. Transgressive phases of this second cycle of sedimentation are unrepresented in Kansas for reasons outlined above, but are represented at least in part, farther to the west and northwest in Colorado and the Black Hills. Regressive phases (6) and (7), if ever deposited in Kansas, have been entirely removed by pre-Pliocene erosion.

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*It should be noted that in other regions of the Western Interior the Pierre Shale and Fox Hills Sandstone and equivalent beds contain evidence of two additional cycles of sedimentation not evident in Kansas.

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ROAD LOGS

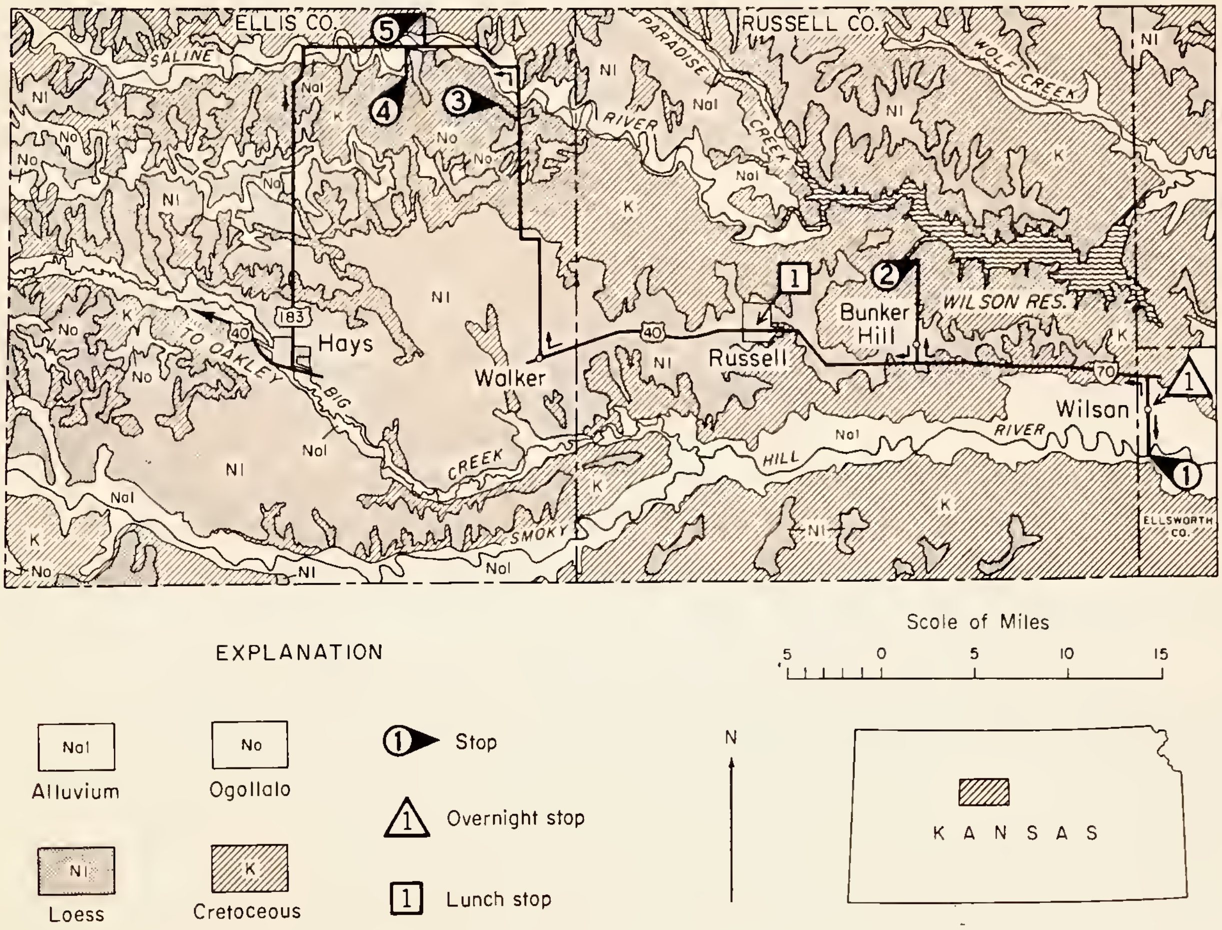
Leaders: Donald E. Hattin (Indiana University)

and W. A. Cobban (United States Geological Survey)

Assisted by Gary F. Stewart (State Geological Survey of Kansas)

Road Log for November 7, 1965

Mileage	
0.0	Flashing light on U.S. Highway 40 in center of Wilson, Kansas. Proceed south on county road.
0.7	Crossing intermediate-level (early Pleistocene) alluvial terrace.
1.4	Fence on right supported by posts quarried from Fencepost limestone bed which lies at top of Greenhorn Limestone.
1.6	Pit on right in intermediate-level terrace alluvium consisting of sand and gravel.
1.8	Pit on left in intermediate-level terrace alluvium.
1.9	Exposures of steeply cross-bedded Dakota sandstone in ditches on both sides of road. Dakota Formation well exposed ahead in bluff on south side of Smoky Hill River.
2.1	Dakota Formation exposed in ditch on right.



Map showing route of first day of trip. Geology modified from Geologic Map of Kansas, 1964.

2.2	Descending from low terrace onto flood plain of Smoky Hill River.
2.4	Tailings at site of abandoned Dakota lignite mine visible in draw at 1 o'clock.
2.6	Crossing Smoky Hill River. Note channel sandstone body in Dakota at right.
2.7	Terrace alluvium on left at south end of bridge.
2.8	Dakota Formation on right. Sandy carbonaceous shale overlain by clean quartzose sandstone.
2.9-3.0	STOP 1.
	Reboard bus at top of hill. Return to Wilson.
6.0	Flashing light in Wilson. Turn right (east).
6.3	Junction with Kansas Highway 232. Turn left (north) on K-232.
7.0	Early Pleistocene alluvium exposed in roadside ditches.
7.6	Dakota Formation exposed in roadside ditch on right. Contains fragmentary pieces of limonitized wood and sparse impressions of angiosperm leaves.
7.8	Dakota in ditch on right.
8.1	Overpass at Interstate Highway 70. Turn left (west) onto westbound ramp at north end of overpass.
8.3-8.5	Dakota Formation poorly exposed in roadbank on right.
8.8	Ascending escarpment held up by Greenhorn Limestone.
9.1	Entering Russell County.
9.8	Greenhorn Limestone poorly exposed in roadside ditch on right.
10.1-10.3	Greenhorn Limestone exposed in deep roadcut. Upper part of Hartland Shale Member through lower part of Pfeifer Shale Member.
11.0	Underpass.
11.0-11.2	Upper part of Jetmore Chalk Member and lower part of Pfeifer Shale Member exposed in roadcut.
11.9-12.0	Weathered lower part of Fairport Chalk Member of Carlile Shale poorly exposed in roadcut. (Marker bed known as "pink lime" is exposed here).
12.1	View west across upland surface of Smoky Hills.
12.5	Bluff on south side of Smoky Hill River visible in distance on left.
12.9	Underpass.
12.9-13.2	Jetmore Chalk Member and lower part of Pfeifer Shale Member exposed in roadcut.
14.3	Dorrance exit. Cuts in upper part of Jetmore and lower part of Pfeifer. Abandoned quarry in Fencepost limestone in pasture northeast of exit.
15.4-15.5	Upper two-thirds of Hartland and lower part of Jetmore exposed in roadcut.
15.6-15.7	Roadcut in Jetmore Chalk Member.
15.9	Overpass.
16.4	Overpass above tracks of Union Pacific Railway Co.
16.6	Temporary end of I-70. Proceed westward on U.S. 40.
17.9	Lower part of Fairport poorly exposed in roadcut on left. *Collignoniceras woollgari*.

19.2	Jetmore Chalk Member exposed in small roadcut.
20.8	Crossroad. Turn right (north) on Bunker Hill-Luray Road.
21.5	Entering Bunker Hill, Kansas.
22.1	Grade crossing at Union Pacific Railway line.
23.2	Lower part of Fairport exposed in roadside ditch on right. (*Inoceramus cuvieri*, *C. woollgari*, burrows, *Ostrea*; "pink lime" exposed here).
23.3	Lower part of Fairport exposed in roadside ditches. Loessial soil lies above Fairport.
23.9-24.1	Upper part of Pfeifer and lower part of Fairport exposed in long roadcut. Fencepost limestone bed conspicuous in middle of section.
24.2	Upper two-thirds of Hartland and lower part of Pfeifer exposed on right in cutbank of intermittent stream. Roadcut ahead is in upper part of Pfeifer and lower part of Fairport.
24.6	Note use of stone posts in fences on both sides of road.
24.9-25.4	STOP 2.
25.9	Reboard bus at top of hill. Return to U.S. Highway 40.
30.0	Junction with U.S. Highway 40. Turn right (west) onto U.S. 40.
30.9	Upper part of Jetmore in low roadcut.
37.6	East city limit of Russell (originally called Fossil Station).
37.8	Historical marker commemorating construction of the Union Pacific railroad in 1867 and an Indian ambush in 1869 during which two of seven railroad section hands were killed and four others were wounded.
38.6	Junction of U.S. 281 (Fossil Avenue) and U.S. 40. Continue westward on U.S. 40.
38.9	Crossroad at Lincoln Street. Turn right onto Lincoln Street.
39.1	Entrance to city park. Turn left into park. Lunch stop.
39.4	Park entrance, turn right (south) and return to U.S. Highway 40.
39.6	Junction Lincoln Street and U.S. 40. Turn right (west) onto U.S. 40. Oil field on both sides of highway is part of Russell oil field, producing from rocks of the Arbuckle Group (Cambrian-Ordovician) and the Kansas City and Lansing Groups (Pennsylvanian) on the Central Kansas Uplift. For next several miles route crosses loess-veneered Cretaceous rocks.
47.6	Gorham oil field on left. Extensive deeper drilling in early 1960's resulted in renewed production in this part of field.
48.1	Entering Gorham, Kansas.
49.2	Entering Ellis County.
51.1	Entering Walker, Kansas.
51.2	Turn right (north) on county road. (If roads are wet, alternate route will be followed west to Victoria, thence north to Saline River valley, thence southeast to Stop 3 via Saline Valley Road.) For next several miles route crosses loess-covered Carlile Shale.
53.5	Crossroad. Hills on horizon to north are capped by Fort Hays Limestone Member of Niobrara Chalk.
57.5	"T" intersection. Turn left (west).
58.5	Crossroad. Turn right (north).

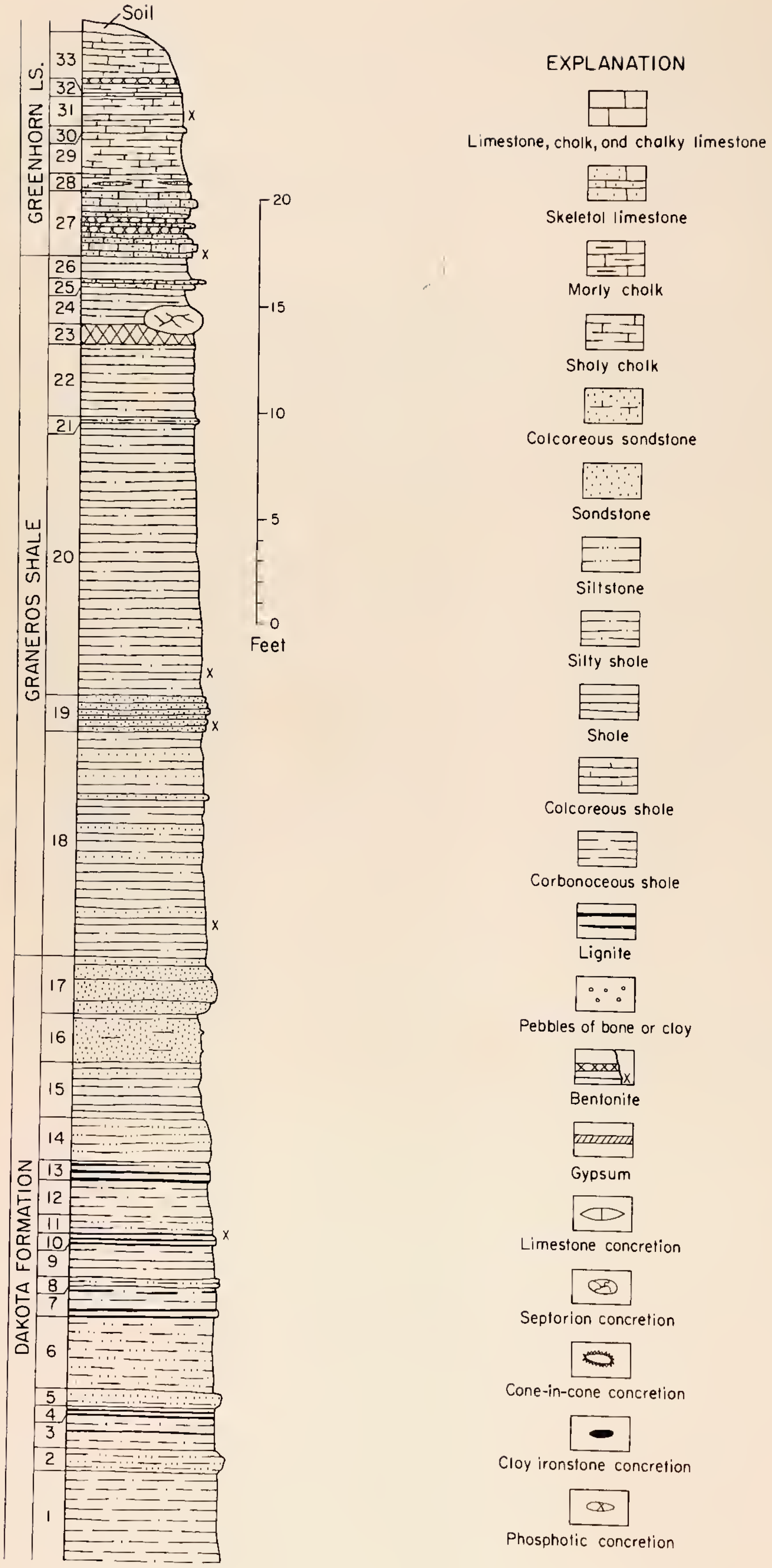


Figure 8.- Graphic column of rocks exposed at Stop 1, East $\frac{1}{2}$, NW sec. 6, T 15 S, R 10 W, Ellsworth County, Kansas. Section measured by Donald E. Hattin and assistants 1960, 1964. For description of this and subsequent graphic columns, see Appendix.

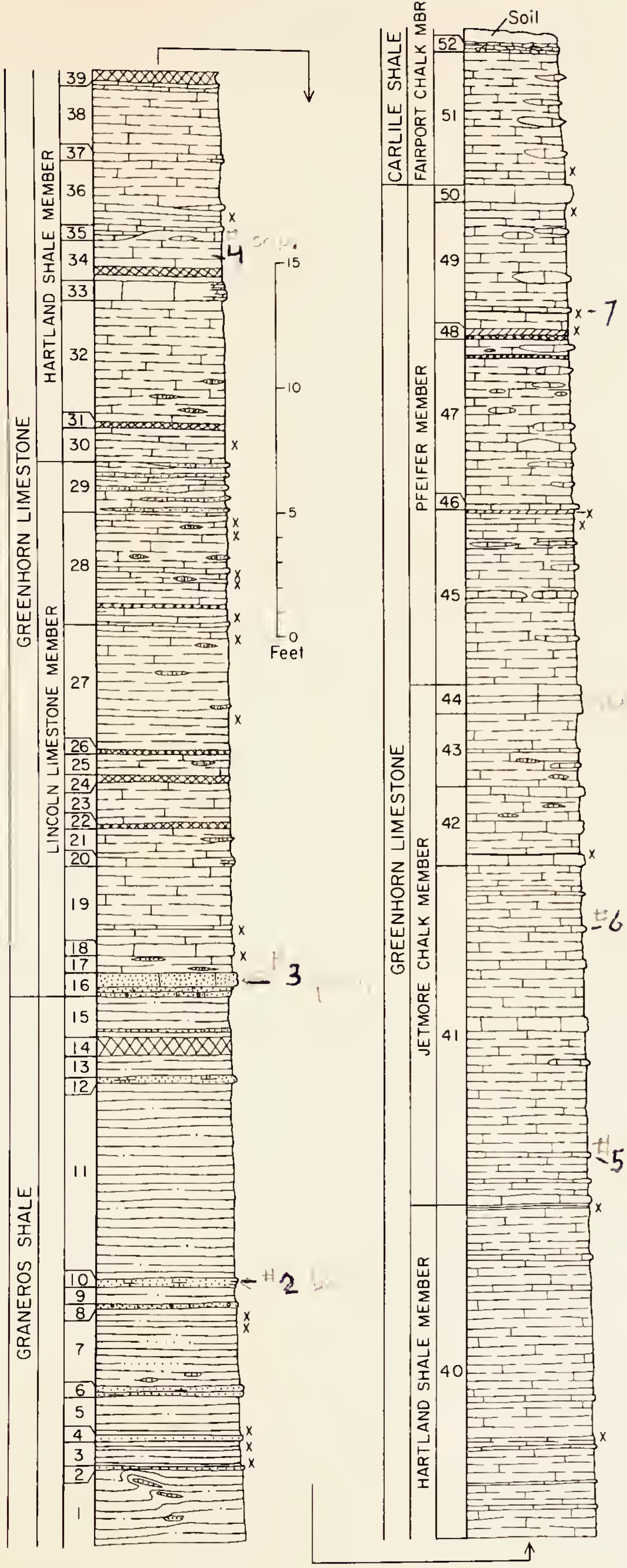


Figure 9.- Graphic column of rocks exposed at Stop 2, center west line sec. 18, T 13 S, R 12 W, Russell County, Kansas. Section measured by Donald E. Hattin and assistants, 1962, 1964. For explanation of this and subsequent graphic columns, see Figure 8.

59.1-59.3	Ascending Fort Hays Escarpment. Codell Sandstone Member of Carlile Shale, exposed in ditches at 59.2, consists of soft argillaceous siltstone. Extensively burrowed chalky limestone in ditch on left at 59.3 is basal part of Fort Hays Limestone Member of Niobrara Chalk.
60.1	Fort Hays Member exposed on both sides of road.
60.2	Codell-Fort Hays contact exposed in pasture on right.
60.3	Large septarian concretions in pasture on right are in upper part of Blue Hill Shale Member of Carlile Shale.
60.4	View across Sweetwater Canyon toward Fort Hays Escarpment at 11 o'clock.
60.7	Blue Hill, Codell, and Fort Hays exposed in pasture on right. View left to Fort Hays Escarpment.
61.0	Small hill in pasture on left is slump block capped by limestone of the Fort Hays.
61.2	Zone of grayish-orange to dark-yellowish-orange septarian concretions is in middle part of Blue Hill Shale Member.
61.4	Steep hill shortly west of road capped by limestone of the Fort Hays showing normal lithology at south end and on flanks of hill. Steeply south-dipping limestone at north end of hill apparently has been altered by ground-water action. Anomalous dip has resulted from slump-block tilt and/or frost action.
62.0	Crossing stream in Sweetwater Canyon. Bench on right underlain by Fairport Chalk Member of Carlile Shale and thinly veneered by loesslike silt. Fresh exposure of Fairport at left rear (7 o'clock).
62.3	View ahead across Saline River valley to bluffs on north side of valley. Good view of Fort Hays Escarpment at 10 o'clock.
62.5	Crossroad at Blue Hill School.
62.6	Weathered Fairport exposed in Sweetwater Canyon on right.
63.1	Weathered Fairport exposed in roadside ditch on right.
63.9	Middle part of Fairport exposed in roadside ditch on right. *Inoceramus*, *Ostrea*, *Stramentum*.
64.7	Middle part of Fairport exposed in small canyon on right. *Inoceramus*, *Ostrea*, reptile bones near road.
64.9	Cattle guard on left. Turn left (west) into pasture and follow lease road. Fort Hays Escarpment straight ahead. Blue Hill Shale Member of Carlile is approximately 215 feet thick in this bluff.
65.9	Cattle guard and gate. Pull onto faint trail on right just past cattle guard. STOP 3.
	Turn around and retrace lease road to county road.
66.9	Cattle guard, turn left (north) on county road.
67.3	Roadcut and stream bank on right exposing section from upper part of Jetmore to lower part of Fairport. Note ditch on hillside to left where Fencepost limestone was quarried.
67.4	Crossing Saline River.
68.5	Crossroad, proceed straight ahead.
69.0	Weathered Blue Hill Shale Member exposed in roadside ditch on right.
69.2-69.4	High-level terrace gravel exposed in roadcuts. Weathered Fairport exposed in ditch at north end of cuts.

69.5	Road junction, turn left (west) and descend to lower level alluvial terraces of Saline River.
70.3	Road curves to north.
70.4	Sand and gravel of lower alluvial terrace exposed in roadbank on right.
70.8	Road junction. Turn left (west). For next half a mile route crosses the lowest terrace of the Smoky Hill River. A low spot on the streamward edge of this terrace has been inundated by flood waters only once (1928) in the memory of the elderly owner of this property.
71.6	Terrace alluvium consisting of sand and gravel exposed in pit on left.
71.7	Terrace alluvium exposed in low roadcut on right. Note terrace surface on left.
71.9	Terrace alluvium exposed in bluffs on both sides of road.
72.0-72.2	Loessial soil in roadcut on right. High-level terrace alluvium exposed in pits at 10 o'clock.
72.7	Terrace alluvium exposed in roadcut on left.
73.2	Crossing Saline River. Oil wells in vicinity are in Bemis-Shutts oil field.
73.4	Terrace alluvium exposed in roadcut.
73.6	Norman Cemetery on right.
75.1	Crossroad, proceed straight ahead on Saline Valley Road.
75.3	High-level terrace alluvium exposed in low roadcut.
75.5	Middle part of Fairport exposed in ditch north of culvert.
75.6	Exposure of high-level terrace alluvium.
75.7	High-level terrace alluvium exposed in small pit and roadcut on right.
75.8	View of low alluvial terrace ahead and to right. Flood plain on far right.
76.2	Lease road on left leading to Bemis oil field. Turn left onto Bemis Ranch.
76.3	Cattle guard.
76.8	Blue Hill Shale Member of Carlile exposed in gullies on right. Exposure of Fort Hays Limestone Member straight ahead caps slump block.
77.2	Cattle guard.
77.5	Wooden bridge.
77.6	"Y" in road. Turn right on secondary oil field road. Oil is produced here from Arbuckle, Simpson, and Kansas City-Lansing rocks. Initial production was in 1935. Shutts pool production, a short distance to the east, began in 1926.
77.8	STOP 4. Watch for rattlers!

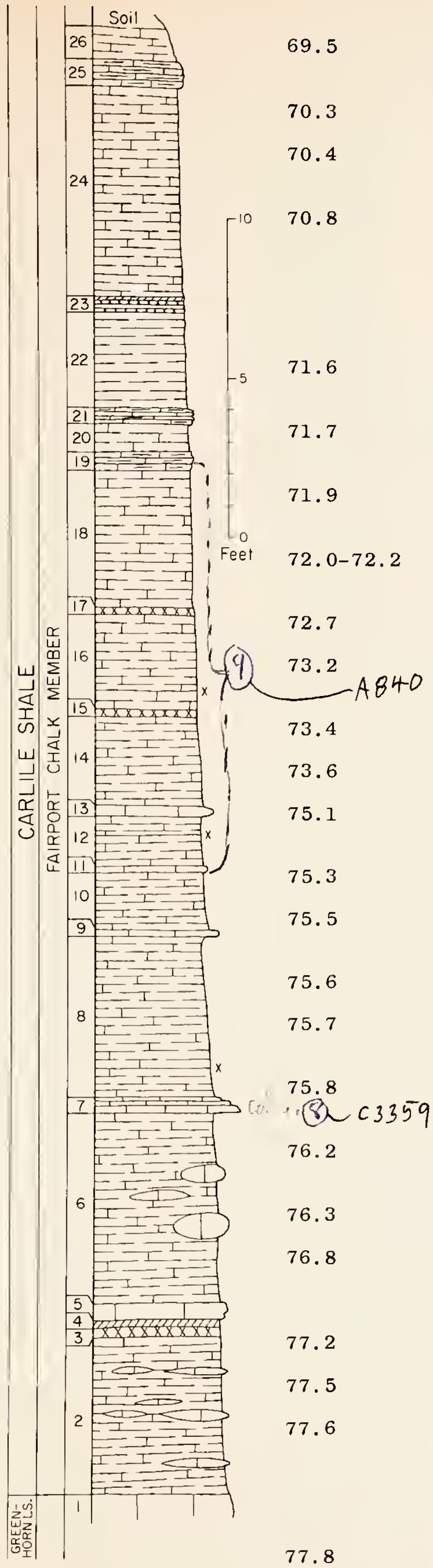


Figure 10.- Graphic column of rocks exposed at Stop 3, SW SW sec. 28, T 11 S, R 16 W, Ellis County, Kansas. Section measured by Donald E. Hattin and assistants, 1959.

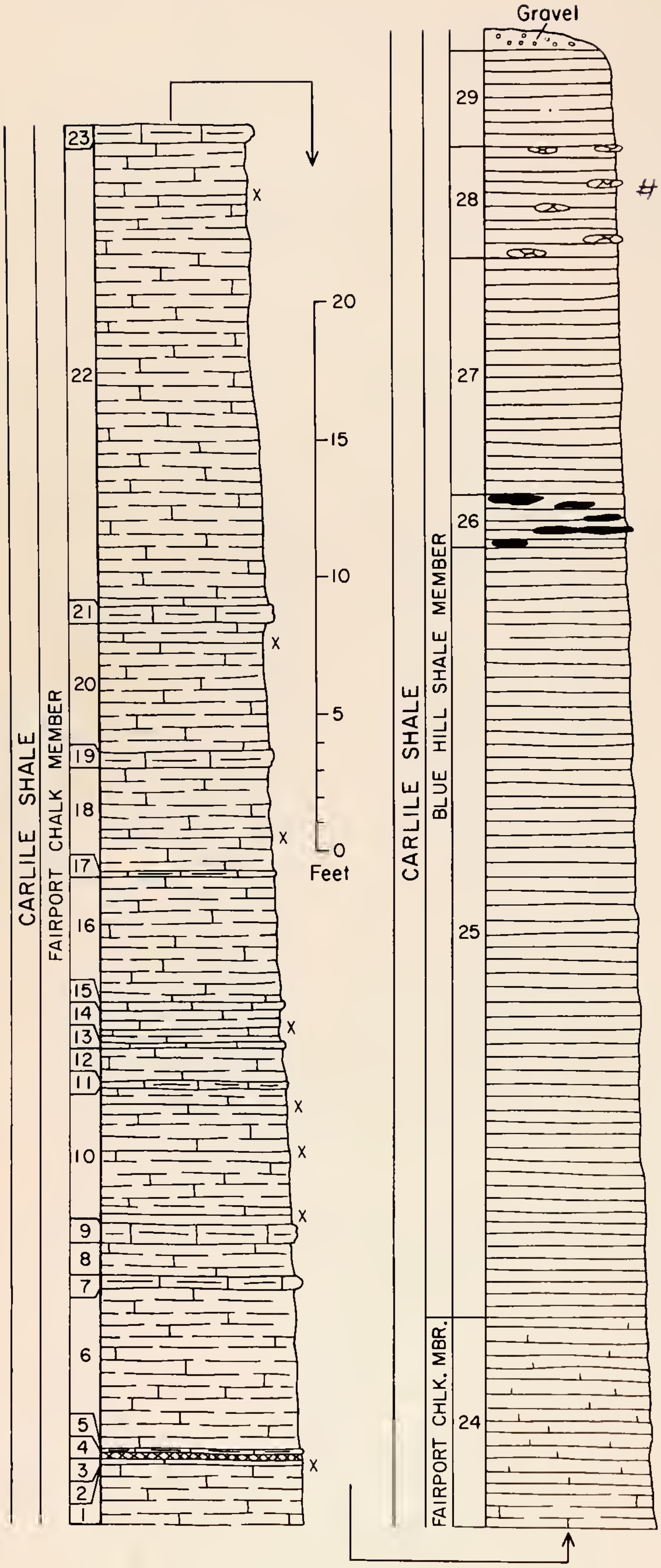


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Figure 11.- Graphic column of rocks exposed at Stop 4, E½ sec. 21, T 11 S, R 17 W, Ellis County, Kansas. Section measured by Donald E. Hattin and assistants, 1959.

	Retrace lease road to Saline Valley Road.
79.3	Junction of lease road and Saline Valley Road. Turn right (east) on latter. Proceed to crossroad at mileage 75.1
80.4	Crossroad. Turn left (north) across Saline River.
80.7	Crossing Saline River flood plain (flooded in 1929, 1957).
81.1	Ascending to level of high alluvial terrace.
81.5	Loessial soil exposed in roadside ditch on right.
81.9	Note pediment surface to right and left.
82.3	Base of King Hill. STOP 5.
82.5	Reboard bus at top of hill and retrace route to lease road at Bemis Ranch (mileage 76.2).
84.6	Crossroad just south of bridge across Saline River. Turn right on Saline Valley Road.
85.7	Lease road leading to Bemis oil field. Proceed straight ahead on Saline Valley Road through cut in loess on both sides of road and cross Saline River.
85.8	View of modern flood plain of Saline River on both sides of road (flooded extensively in 1929 and 1957).
86.2	Entrance to U-Bar (Bemis) Ranch (1883).
86.4	Blue Hill shale overlain by high-level terrace alluvium in roadcuts.
87.0	Pits in terrace alluvium on both sides of road.
87.1	Crossing Saline River.
87.4	View south to bluff exposing upper part of Blue Hill, Codell, and Fort Hays.
87.5	Crossing Saline River.
87.8	Crossing low terrace of Saline River.
88.0	High-level terrace alluvium on left, south of hilltop. View ahead to low terrace.
88.5	Descend from low terrace to flood plain.
88.7	Cross Saline River. Terrace alluvium overlain by loess in cut on left just west of bridge.
88.9	Crossing flood plain of Saline River.
89.2	Crossing Saline River.
90.2	Terrace alluvium in roadcut.
90.3	Crossing low terrace of Saline River for next 0.6 mile.
91.0	Junction of Saline Valley Road and U.S. Highway 183. Turn left (south) on U.S. 183. To north, where U.S. 183 ascends north bluff of Saline Valley, upper part of Blue Hill, Codell, and Fort Hays are exposed in deep roadcut.

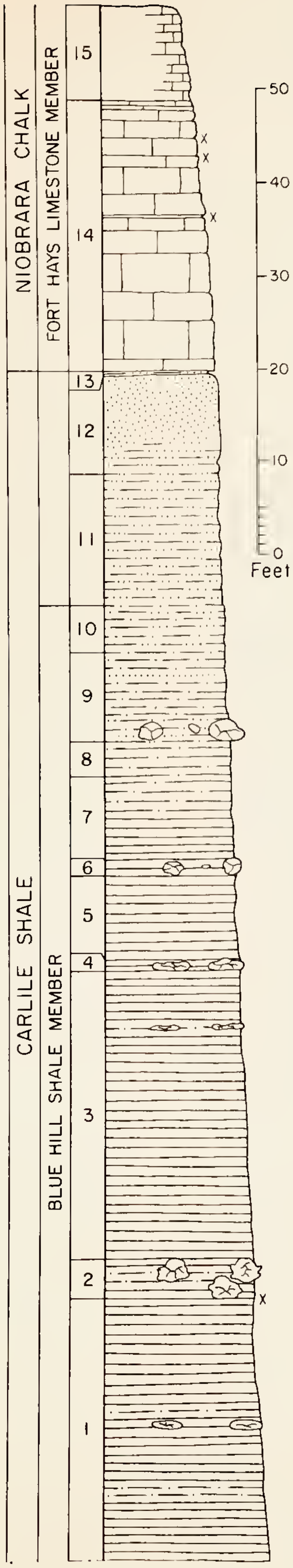


Figure 12.- Graphic column of rocks exposed at King Hill (Stop 5), NE sec. 3, T 11 S, R 17 W, Ellis County, Kansas. Section measured by Donald E. Hattin and assistants, 1959, 1961.

Road Log of Short Side Trip to Famous Collecting Locality in Blue Hill Shale Member of Carlile Shale

0.0	Junction of Saline Valley Road and U.S. Highway 183. Proceed westward on county road.
0.1	Crossing Saline River.
0.5	Crossroad. Turn right (north).
0.7	Crossing Saline River onto flood plain.
0.9	Ascending onto low terrace. High alluvial terrace in middle ground to left (west) ascends northward and merges with relatively steeply sloping surface that is probably a flanking pediment.
1.3	Blue Hill, Codell, and Fort Hays exposed in bluff on left at 10 o'clock. Large slump block capped by Fort Hays at 10:30.
1.4	Descending to flood plain of small tributary of Saline River.
1.5	Abandoned farm house on right. STOP. Walk across pasture on left to cutbank in Blue Hill Shale Member of Carlile Shale. Turn around and retrace route to U.S. 183.
2.5	Crossroad, turn left (east).
3.0	Junction of county road and U.S. 183. Turn right (south).

91.2	Crossing flood plain of Saline River.
91.4	Crossing Saline River.
91.5-91.6	High-level terrace alluvium in roadcut.
91.8-92.0	Loessial soil in roadcut.
92.5	Blue Hill shale overlain by (ascending) alluvium (chalky limestone gravel), loess, and colluvium.
93.2-93.5	Upper part of Blue Hill, Codell, and lower part of Fort Hays in roadcuts on right. Note slumped rock.
93.8-93.9	Upper part of Blue Hill, Codell, and lower part of Fort Hays exposed in large roadcut on right. Normal fault near center of north part of cut has displaced Fort Hays downward (relatively) so limestone lies opposite Codell. Low area between north and south parts of cut is a small colluviated valley with Fort Hays slumped to north at south side of old valley. Note channel-like structure near south end of cut.
94.0	Codell-Fort Hays contact exposed in roadcut on right.
94.1-94.3	Fort Hays Limestone Member of Niobrara Chalk exposed in cut on right. Fort Hays colluvium visible at north end of cut. Note channel-like structure near south end of cut.
94.4-94.5	Fort Hays exposed in low roadcut. Ogallala Formation caps hill west of highway.
95.1	Crossroad.
95.2-95.5	Ogallala Formation exposed in low roadcuts.
95.7	Smoky Hill Chalk Member of Niobrara Chalk exposed in low roadcut on left.
95.9	Smoky Hill exposed in roadcut on left.
96.1-96.3	Smoky Hill exposed in roadside ditches. For next several miles highway crosses upland surface of High Plains.
99.3	Weathered Fort Hays exposed in roadside ditch on right.

100.9-101.0	Fort Hays exposed in long low roadcut. Note slump structure on left and channel-like structures near south end of cut.
102.4	Loess exposed in low roadcut on left.
102.7-102.8	Much-fractured Fort Hays exposed in roadcut on left.
103.0-103.1	Much-fractured Fort Hays exposed in roadcut on left.
103.5-103.6	Much-fractured Fort Hays exposed in roadcut on right. Note channel-like structure near center of cut.
103.7-103.8	Fort Hays exposed in roadcut. Note small fault at south end of cut on left side of highway.
103.9-104.2	Much-fractured Fort Hays exposed in roadcuts.
105.1	Interstate Highway 70 overpass.
105.9	City limit of Hays, Kansas. End of log for first day. Proceed to Oakley, Kansas for overnight stop.

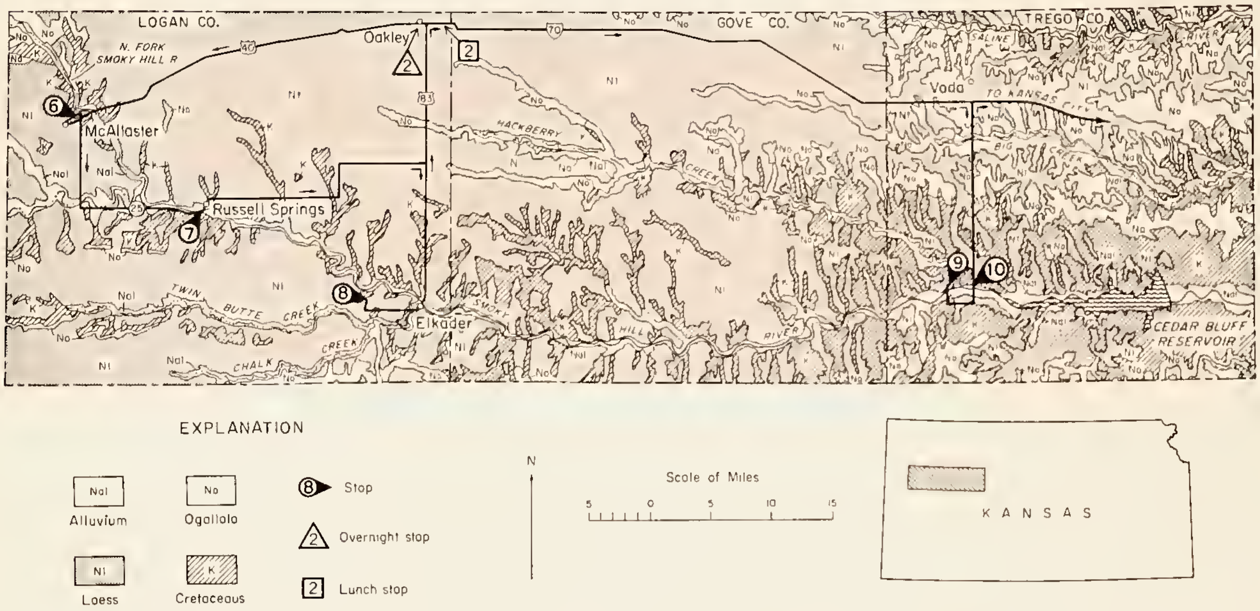
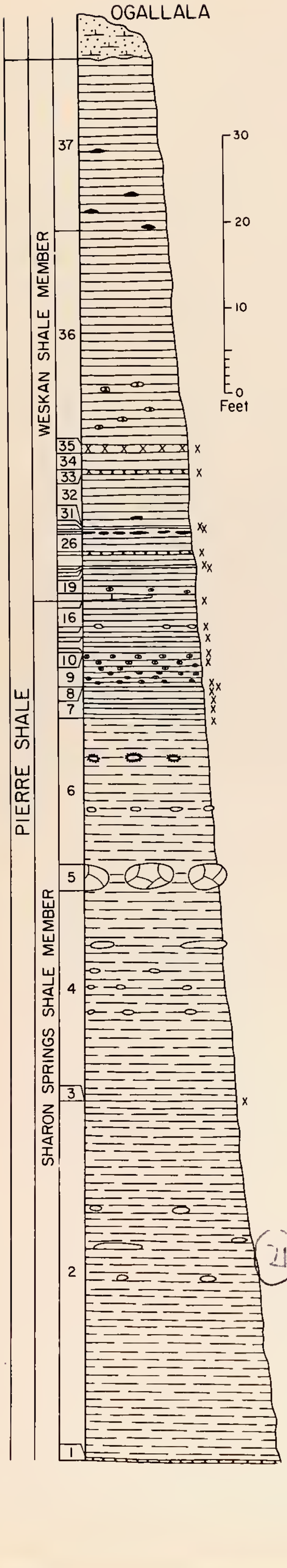


Figure 13.- Map showing route of second day of trip. Geology modified from Geologic Map of Kansas, 1964.

Road Log for November 8, 1965

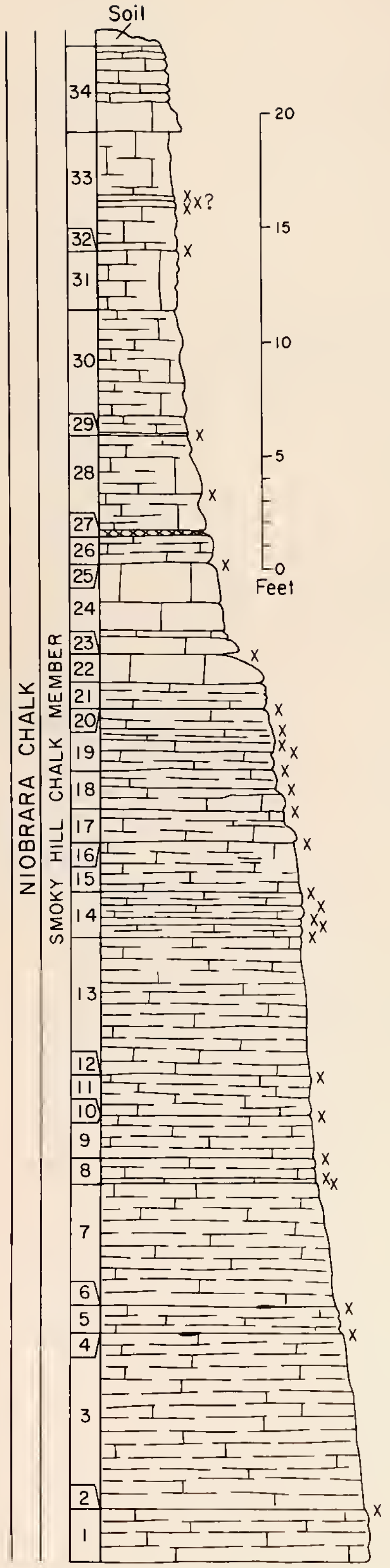
0.0	Junction of U.S. 40 and U.S. 83, Oakley, Kansas. Proceed westward on U.S. 40. For next 27 miles, route crosses loess-veneered upland surface of High Plains.
8.3	Entering Monument, Kansas.
15.9	Entering Page City, Kansas.
17.8	Junction: Kansas Highway 25 turns south. Proceed straight on U.S. 40.
18.4-18.6	Loess exposed in roadcut on left.
21.1	Entering Winona, Kansas.
23.5-23.6	Loess exposed in roadcut on left.
25.1-25.4	Loess exposed in roadcut on right.



25.6-25.8	Loess exposed in roadcut.
26.5-26.7	Loess exposed in roadcut on right. McAllaster Buttes on horizon at 11:30.
27.1-27.3	Sharon Springs Shale Member of Pierre Shale, overlain by loess, exposed in roadcut. Excellent exposure of the Sharon Springs in pasture north of highway.
27.6	Crossing North Fork of Smoky Hill River.
28.3-28.5	Stratified Pleistocene sand and gravel (Crete Formation) overlain by loess (Loveland Formation) in roadcut. McAllaster Buttes at 1 o'clock.
29.9	Entering McAllaster, Kansas.
30.2	Dirt road on right. Turn right.
30.3	Junction, dirt road and abandoned U.S. Highway 40. Turn right on old U.S. 40.
31.3	Gate leading into pasture on north side of McAllaster Buttes. STOP 6.
	Proceed eastward on old U.S. 40.
31.9	Crossroad. Turn right (south) on county road.
32.8	Junction county road and U.S. Highway 40. Cross U.S. 40 and proceed south on Logan County Highway 391.
33.1	Pierre Shale exposed in low roadcut on right.
33.3-33.5	Loess exposed in roadbank on left. For next several miles route crosses upland surface of High Plains.
36.5-36.7	Loess exposed in roadcut on left.
36.8	Loess exposed in roadbank on right.
38.0	Valley of Smoky Hill River marked by line of trees ahead.
38.5	Margin of low alluvial terrace.
39.2	Crossing Smoky Hill River, which is an intermittent stream in this area.
39.4	Upper part of Smoky Hill Chalk Member of Niobrara Chalk exposed in roadcuts. Chalk is overlain by sand, gravel and loess of alluvial terrace. Note exposures of weathered Smoky Hill in bluffs on right at 2:30.
39.5	Smoky Hill overlain by thin loess veneer exposed in low roadcut.
39.9	Junction Logan County Highway 391 and Kansas Highway 25. Turn left (east) on K-25.
㉑ 40.1 asperiformis	Pierre Shale exposed in small fault block and overlain by loess.

Figure 14.- Graphic column of rocks exposed at McAllaster Buttes (Stop 6), SE sec. 13, T 12 S, R 37 W, Logan County, Kansas. Section measured by James E. Gill, U. S. Geological Survey.

40.4	Crossing low alluvial terrace of Smoky Hill River.
41.0	Terrace alluvium overlain by loesslike silt exposed in roadcut on right.
41.2	Sloping surface on right is a flanking pediment.
41.3-41.4	Smoky Hill Chalk Member exposed in roadcut and mantled by loess. Chalk contains Inoceramus and Ostrea.
41.6	Loess and terrace alluvium poorly exposed in cut on right.
41.9-42.1	Terrace alluvium poorly exposed in roadcut.
42.2	Crossing low alluvial terrace.
42.3	Smoky Hill Chalk Member exposed ahead and to left in cliffed bluff overlooking valley of Smoky Hill River. Note anomalous dips owing to flexure.
42.8-43.1	Smoky Hill Chalk Member, Pierre Shale, and loess exposed in long, deep roadcut. Normal fault at 43.0 dropped Pierre to level of Smoky Hill Member. Pierre overlain by thick deposit of loess.
43.3	Erosional pillar of Smoky Hill in pasture on right.
43.6	Gullied alluvial terrace on left.
43.8	Terrace alluvium exposed in arroyo on right. Just east is roadcut in loess overlain by alluvium (sand) of high-level terrace. Note buried soil (dark) within loess.
44.0	Note relatively steep dip in exposure of Smoky Hill Member in bluff of Smoky Hill River at 10 o'clock.
44.1	Weathered Smoky Hill overlain by (ascending) loess and terrace alluvium (sand), all exposed in roadside ditch on right. Note buried soil (dark) in loess.
44.4	Terrace alluvium (sand), and silt (probably loess), exposed in low roadcut.
44.8-44.9	Smoky Hill Chalk Member, Pierre Shale, and loess, exposed in roadcut. Pierre slope littered with large selenite crystals.
45.2	Loess exposed in roadcut on right.
45.5	Crossing low alluvial terrace of Smoky Hill River.
47.8	Junction Kansas Highway 25 and Logan County Highway 407. Proceed on K-25.
48.8	Smoky Hill Chalk Member exposed in bluffs on right at 2 o'clock.
48.9	Smoky Hill veneered by colluvium of small flanking pediment in low roadcut.
49.2	Smoky Hill Chalk Member and overlying alluvium well exposed in arroyo on right. Cap rock on cliff is weathered Smoky Hill.
49.5	Top of small rise; pull onto small ramp on right. STOP 7. Cuts directly ahead are terrace gravel and sand veneered by colluvium of flanking pediment developed around badlands that comprise Stop 7. A modern bison skull has been discovered in this colluvium and can be seen in the pasture.
	Reboard bus and proceed eastward on K-25.
49.7-49.8	Smoky Hill Chalk Member, overlain by terrace gravel, sand, and silt, exposed in roadcut.
50.0	Crossing Smoky Hill River. Beyond bridge route ascends gradually from flood plain to low alluvial terrace.
50.5	Smoky Hill Chalk Member, overlain by terrace alluvium, exposed in roadcut on right.
50.6	City limit of Russell Springs, Kansas.



50.7	Turn right at sign advertising Wycoff Service Station. Courthouse on left abandoned recently when seat of county government was moved to Oakley.
51.4	"T" intersection at east edge of Russell Springs. Turn left (north). Smoky Hill Chalk Member and terrace alluvium (gravel, sand, and silt) exposed in roadcuts on right for next 0.3 mile.
51.9	Turn right at bend in county road.
52.0	Loess exposed in low roadcut. For next 2.6 miles route crosses loess-mantled upland surface of High Plains.
54.7	Bridge across intermittent stream. Smoky Hill Member, overlain by alluvium and loess, exposed in roadcuts and road ditches.
55.6	Bridge. Alluvium and loess exposed in roadcuts.
56.8	Loess exposed in roadcut.
56.9	Smoky Hill Member, overlain by alluvial sand and gravel, exposed in roadcut. Note badlands in Smoky Hill Member approximately a quarter of a mile south of road.
57.0	Bridge.
57.2	Smoky Hill Member exposed in bluffs south of road.
58.9	Smoky Hill Member exposed in small quarry on left and in roadside ditch on right.
59.2	Loess exposed in roadside ditch on right.
61.1	Smoky Hill Member exposed in draw on both sides of road at bridge.
61.5	County road intersection. Turn left (north). Crossing loess-veneered upland surface of High Plains for several miles.
64.5	Bend in road. Turn right (east).
67.3	Crossroad. Proceed straight ahead.
71.3	Junction county road and U.S. Highway 83. Turn right (south) on U.S. 83.
73.7	Loess poorly exposed in roadcut on left.
74.2	Bridge. Loess exposed in roadcut just south of bridge.
74.7	Loess poorly exposed in roadcut.
75.3	Crest of hill. Valley of Smoky Hill River visible in distance. Loess exposed in cut on left.
76.5	Side trail on left. Smoky Hill Member exposed in draw on both sides of highway.

Figure 15.- Graphic column of rocks exposed at Goblin Hollow (Stop 7). $E\frac{1}{2}$ sec. 27, T 13 S, R 35 W, Logan County, Kansas. Section measured by Donald E. Hattin and Gary F. Stewart.

(3 miles S on Twin Butte Cr,
excellent Smoky Hill exposures.

76.8	Loess exposed in roadcut on left.
77.0	Road construction materials area on left.
77.3	Smoky Hill Member exposed in draw on left at 10 o'clock.
78.5	Smoky Hill Member exposed in many places in large draw on right.
79.3	Bridge across draw.
79.4	Unconformity between Smoky Hill Member and Pleistocene loess exposed in roadcut on left.
79.5	Smoky Hill Member well exposed in miniature badlands on left.
80.1	Abandoned schoolhouse on right. Road to left at large sign leads to erosional features in Smoky Hill Chalk Member known as "Monument Rocks" and "Sphinx."
80.8	Loess exposed in roadcut on left. Badlands cut into Smoky Hill Member in draw on right.
81.0-81.2	Loesslike silt exposed in roadcut on left.
81.7-81.8	Alluvium, overlain by pebbly silt (colluvium), exposed in roadcut on left. Smoky Hill Member exposed in low roadcut ahead.
81.9-82.1	Smoky Hill Member, overlain by high-level terrace gravel, in roadcuts and natural exposures.
82.2	Crossing low alluvial terrace of Smoky Hill River. Note stone post on left, ahead, marked B.O.D. 1865. This and several similar posts on other well-travelled roads in the area mark the Smoky Hill Trail and route of the Butterfield Overland Dispatch, a stage line that served the Smoky Hill River country from June 1865 to March 1866. The line was then sold to the Holiday Overland and Express Company and finally to The Wells Fargo & Co. Indian attacks and railroad construction terminated stage-line operations.
82.4	Bridge across Smoky Hill River.
82.7	Elkader, Kansas.
82.9	Low terrace alluvium, mantled by colluvium, exposed in roadcut on left.
83.1	High-level terrace alluvium (gravel and sand) in roadcut on right.
83.2	Junction U.S. Highway 83 and Logan County Highway 474. Turn right (west) on L-474. First cuts on L-474 are in high-level terrace alluvium.
83.5	Bridge across Ladder Creek.
84.1	High-level terrace alluvium (gravel) exposed in roadcut.
84.2	Loess exposed in roadcut.
86.5	Smoky Hill Member (middle part) exposed in badlands on left.
87.6	"T" intersection. Turn right (north).
88.1	Bend in road at gate leading into pasture. Turn right onto trail leading into unfenced range.
88.7	Wire gate at end of trail. STOP 8. Cross fence and walk through pasture to head of closest canyon.
	Turn around and retrace trail to county route.
89.3	Junction trail and county road. Retrace county roads to U.S. 83.
94.3	Junction Logan County 474 and U.S. 83. Turn left (north) on U.S. 83. Retrace route to junction with road to Russell Springs.

106.2	Junction U.S. 83 and road (left) to Russell Springs. Road on right leads to Gove City. Proceed straight ahead on U.S. 83.
108.2	Ogallala Formation exposed in draw on right.
108.7-108.9	Ogallala Formation, overlain by Pleistocene alluvium (sand) and loess, exposed in deep roadcut.
109.0	Bridge.
109.2-109.3	Loess poorly exposed in roadcut on left.
109.8	Crossing loess-veneered upland surface of High Plains from here to Oakley.
111.9	Alluvium (sand), overlain by loess, exposed in roadcut. Ogallala Formation exposed in draw on right.
113.9	Loess exposed in roadcut.
116.6-116.7	Loess exposed in roadcuts.
116.9	Junction U.S. Highways 83 and 40 at Oakley. Turn right (east) on U.S. 40. From here to Voda route crosses loess-veneered upland surface of High Plains.
118.7	Roadside park. Lunch stop.
118.9	Entering Gove County.
119.0	Junction U.S. 40 and Interstate 70. Turn right onto eastbound ramp of I-70.
139.1	Roadside park on I-70.
149.8	Quinter Interchange. Proceed eastward on I-70.
154.0	Loess exposed in roadcut on right.
155.3	Entering Trego County.
157.8-158.1	Loess exposed in roadcut on right.
159.9	Loess exposed in roadcut on left.
160.6-160.9	Loess exposed in roadcut.
161.9	Voda Interchange. Turn right onto exit ramp.
162.0	Stop sign. Turn right (south) on Voda Road.
164.0	Sandy and pebbly silt (colluvium?) exposed in roadcut on right.
164.1	Pleistocene alluvium and loess exposed in roadcut on left. Prominent buried soil (dark) about halfway between top and base of cut. Conspicuous filled burrow lies in and below this soil zone. Irregular-shaped calcareous nodules abundant in zone below soil. Colluvium? and scattered blocks of Ogallala lie at top of cut.

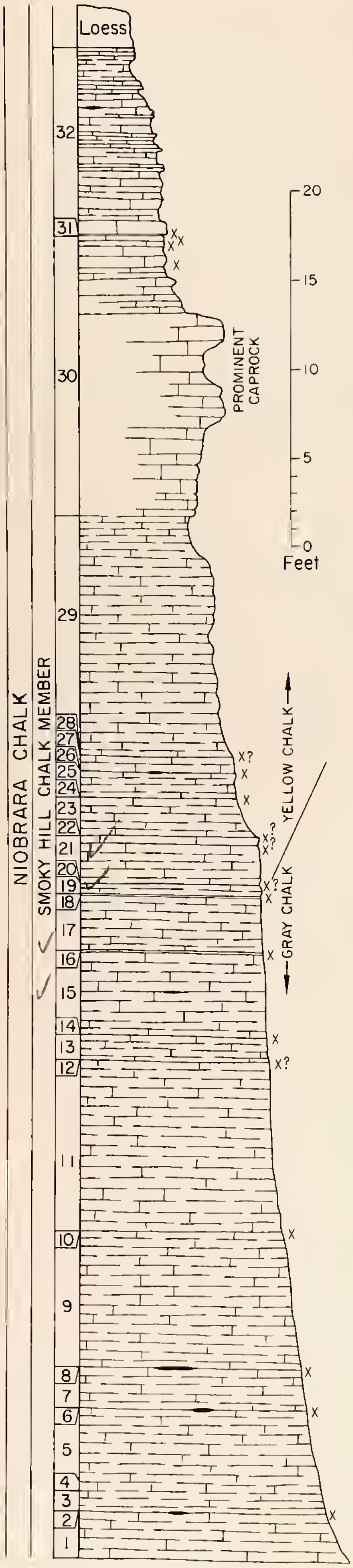


Figure 16.- Graphic column of rocks exposed at Chalk Canyon (Stop 8), SW sec. 25, T 14 S, R 33 W, Logan County, Kansas. Section measured by Donald E. Hattin and Philip H. Heckel, 1965.

164.3	Loess, overlain by alluvial sand, exposed in cut on right.
164.7	Bridge across intermittent stream.
164.8	Ogallala Formation exposed in roadside ditch on right and in graded bank on left.
164.9	Roadcut in sand and gravel deposit derived from Ogallala Formation which closely underlies upland surface in distance on right.
171.4	Junction Voda Road and Trego County Highway 458. Proceed on Voda Road.
175.4	Junction Voda Road and Trego County Highway 462. Proceed on Voda Road.
175.7	View ahead to valley of Smoky Hill River.
176.0	Top of bluff overlooking valley of Smoky Hill River. Smoky Hill Chalk Member exposed in roadcut on left.
176.3-176.4	Fort Hays Member, overlain by colluvium, exposed in roadcuts on left.
176.5	Upper part of Blue Hill Shale Member, Codell Sandstone Member, and lower part of Fort Hays Limestone Member exposed in roadcut on left. We will return to this cut for Stop 10.
176.6	Intermediate-level alluvial terraces of Smoky Hill River visible on left.
176.7	Flood plain of Smoky Hill River. Low-level terrace can be seen at right and right rear. Cross Smoky Hill River.
176.9	Crossing margin of one of intermediate-level terraces. Blue Hill Shale Member exposed in roadside ditch on right, beneath terrace alluvium. Note large septarian concretions in pasture on right.
177.0	Terrace alluvium exposed in roadside ditch and roadbank on right. Note gravel pit in pasture on left. Pit is in the next-to-highest of four terraces that can be readily distinguished on the south side of the river at this point.
177.3	Alluvial sand of high-level terrace exposed in roadcut on right.
177.4	Crossroad. Turn right (west). For next 1.4 miles route crosses surface of highest terrace of Smoky Hill River.
179.1	Fort Hays Limestone Member exposed in roadside ditch and pasture on right.
179.3	Fort Hays Member, overlain by terrace alluvium, exposed in roadside ditch on right.
179.4	"T" intersection. Turn right (north). Fort Hays exposed in pasture and along road on right.
179.6-179.8	Crossing low terraces and flood plain of Smoky Hill River. Cross Smoky Hill River.
179.9	Fort Hays exposed on both sides of road. Ascend steep hill; keep to right.
180.0	Fort Hays exposed in small roadcuts. Fort Hays poorly exposed in several places in next 0.3 mile.
180.3	Wire gate on right. Turn right into pasture and follow trail. At trail "Y", turn right and proceed to top of bluff near mouth of Hackberry Creek.
180.6	STOP 9.

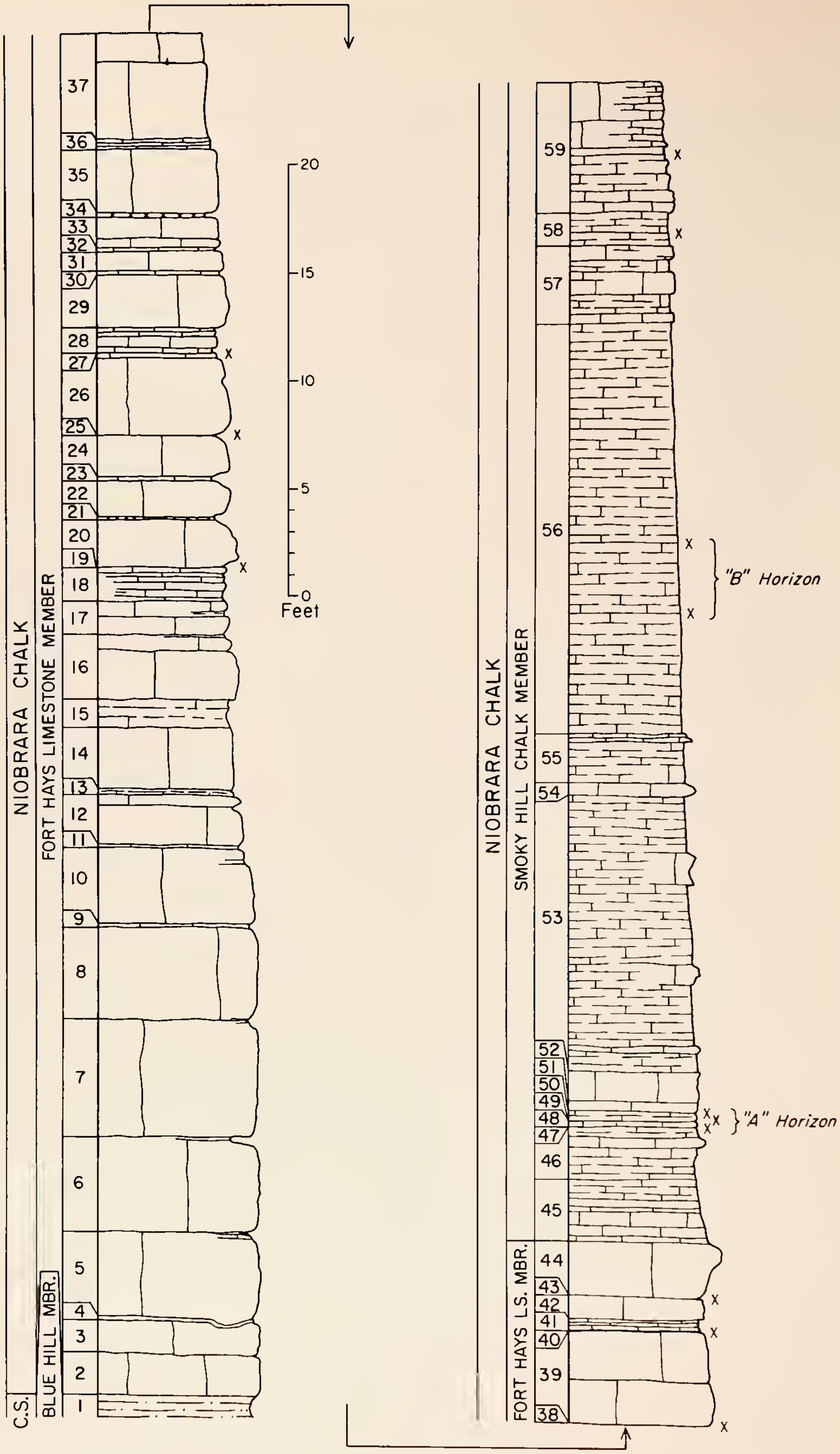


Figure 17.- Graphic column of rocks exposed at Stop 9, SW sec. 24 and NW sec. 25, T 14 S, R 25 W, Trego County, Kansas. Section measured by Donald E. Hattin and Craig Hatfield, 1962.

	Reboard bus 0.3 miles to west and retrace route to Voda Road.
180.9	Wire gate at entrance to pasture. Turn left (south) on county road.
181.8	County road junction, turn left (east).
183.8	Junction of county road and Voda Road. Turn left (north) on Voda Road.
184.5	Crossing Smoky Hill River.
184.7	STOP 10.
	Retrace route to Voda Interchange
199.3	Voda Interchange on I-70. Turn right (east) onto I-70. Proceed eastward toward Kansas City.

End of Road Logs

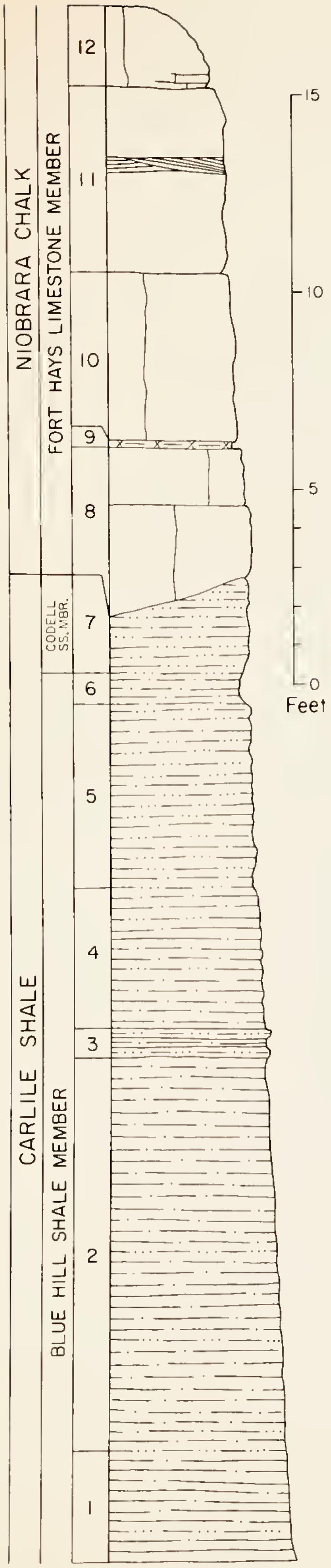


Figure 18.- Graphic column of rocks exposed at Stop 10, NW sec. 29, T 14 S, R 24 W, Trego County, Kansas. Section measured by Donald E. Hattin and Gary F. Stewart, 1965.

APPENDIX

Measured Sections for Field Trip Stops

Descriptions of sections at the various stops mostly have not been published hitherto and are included here to benefit field trip participants as well as future visitors to this area.

Description of Section Measured at STOP 1

GREENHORN LIMESTONE

	Lincoln Limestone Member	Feet
33.	Shaly chalk, similar to 31; bentonite is 0.2 foot thick, nearly white, weathers dark yellowish orange; FOSSILS - *Inoceramus* sp., fish remains	2.8
32.	Chalk, weathered yellowish gray to dark yellowish orange, soft, laminated, speckled; FOSSILS - *Inoceramus pictus*, fish remains.	0.2
31.	Shaly chalk, weathered yellowish gray to dark yellowish orange, soft, laminated, speckled, with numerous very thin lenses of skeletal limestone; bentonite is 0.13 foot thick, very light gray, slightly silty; FOSSILS - *Inoceramus* sp., fish remains.	1.5
30.	Chalky limestone, weathered grayish orange to dark yellowish orange, soft to medium-hard, speckled, uneven thickness; FOSSILS - *Inoceramus pictus*, fish remains.	0.2
29.	Shaly chalk, similar to 31; FOSSILS - *Inoceramus pictus*, fish remains	1.9
28.	Skeletal limestone and shaly chalk, weathered dark yellowish orange; limestone is very fine grained, hard, thinly laminated, in very thin lenses and lensing layers; chalk soft, laminated; FOSSILS - *Inoceramus* sp., fish remains	0.7
27.	Skeletal limestone and bentonite; limestone is light olive gray, upper beds weathering pale yellowish brown to dark yellowish orange, hard, limonite-speckled, petroliferous odor, mostly *Inoceramus* shell fragments and prisms; one bed of softer chalky limestone in upper part of unit; bentonite is 0.3 foot thick, light gray to light olive gray; FOSSILS - *Inoceramus pictus*, *Ostrea* sp., fish remains	1.6
	Thickness of exposed part of Lincoln Limestone Member	8.9

GRANEROS SHALE

26.	Shale, similar to 24; FOSSILS - *Inoceramus* sp. (prisms), *Hedbergella*, fish remains.	1.1
25.	Skeletal limestone, light-olive-gray weathering dark yellowish orange, well-cemented, quartz sandy, thinly laminated to gently cross-laminated, petroliferous odor where fresh, composed largely of *Inoceramus* prisms; FOSSILS - *Ostrea beloiti*, *Inoceramus rutherfordi*, *Plesiacanthoceras* sp., fish remains.	0.3
24.	Shale, weathered light olive gray to dark yellowish orange, streaked with very fine grained quartz sand or silt, soft, with specks of carbonaceous matter; FOSSILS - *Inoceramus* sp., *Ostrea* sp., *Hedbergella*, *Heterohelix*, fish remains	1.4
23.	Bentonite and septarian concretions; bentonite 1.0 foot thick, very light gray weathering dark yellowish orange, slightly silty, speckled with biotite?; concretions dusky-yellow to nearly white, up to 4.0 feet across; FOSSILS - *Ostrea beloiti*, *Inoceramus rutherfordi*.	1.4

22.	Shale, medium-gray to medium-dark gray weathering to dark yellowish orange, quartz silty in lower part, sandy and thinly laminated in upper part; sand argillaceous, occurs in lenses and very thin layers; zone of alunite nodules in upper part; FOSSILS - *Inoceramus rutherfordi*?, *Ostrea beloiti*, *Borissiakoceras*, *Reophax* and *Hedbergella* . . .	3.7
21.	Siltstone, dark-yellowish-orange, discontinuous, quartzose, argillaceous, limonitic, thinly laminated to gently cross-laminated, friable.	0.2
20.	Shale, medium-dark to light-olive-gray weathering medium brownish gray, silty, streaked with thin laminae and lenses of quartz silt or very fine sand, with specks of carbonaceous matter, soft, weathers flaky, streaked locally with limonite; bentonite is 0.08 foot thick; FOSSILS - *Plesiacanthoceras amphibolum*, *Borissiakoceras reesidei*, *Ostrea beloiti*, *Inoceramus* sp., *Reophax*, *Hedbergella*, *Ammobaculites*, *Trochammina* . . . . #, this horiz another loc.	12.7
19.	Sandstone, light-olive-gray weathering moderate yellowish brown, quartzose, alternating well- and poorly cemented beds, softer layers argillaceous with several thin shale partings, with specks of carbonaceous matter, bentonite is 0.08 foot thick, light olive gray to greenish gray; FOSSILS - *Inoceramus* sp., *Callistina lamarensis*, fish remains	1.7
18.	Shale, similar to 20, in part limonite- and jarosite-stained; well-cemented sandstone, 0.1-foot-thick, light-olive-gray, thinly laminated, lies 7.5 feet above base; bentonite is 0.05 foot thick, light gray; FOSSILS - *Callistina lamarensis*, *Inoceramus* sp. (prisms), worm castings, *Reophax*, *Ammobaculoides*, *Trochammina*, *Verneuilinoides*, and *Hedbergella* (last two above sandstone bed only)	11.3
	Total thickness of Graneros Shale	33.8

DAKOTA FORMATION

17.	Sandstone, mostly weathered moderate yellowish brown, quartzose, micaceous, carbonaceous, limonitic, moderately well cemented, argillaceous in upper 1 foot, with numerous clay galls; FOSSILS - *Callistina*? sp. .	2.4
16.	Sandstone and sandy shale; sandstone light olive gray weathering dark yellowish orange, quartzose, argillaceous, carbonaceous, friable, in part limonite cemented and very dusky red in color; shale medium dark gray, in part laminated; FOSSILS - worm? burrows	2.3
15.	Shale, medium-dark-gray, quartz silty, soft, thinly laminated, interbedded in lower 0.8 foot with sandy carbonaceous shale and very thin beds of quartzose sandstone; interbedded in upper 0.8 foot with very thin layers of thinly laminated very fine quartz sand; FOSSILS - *Trochammina*, *Ammobaculites*.	2.6
14.	Siltstone, dark-gray to medium-light-gray, quartzose, argillaceous, sandy, carbonaceous, micaceous, soft, friable; FOSSILS - upright reed? molds in top 0.5 foot	2.1
13.	Lignite, grading upward into carbonaceous silty shale, black to dark-gray.	0.8
12.	Shale, dark-olive-gray, silty, carbonaceous, irregularly streaked with light-olive-gray laminated quartzose siltstone; bedding depressed around numerous upright reed? molds; FOSSILS - reed? molds	1.7
11.	Siltstone, olive-gray to dark-olive-gray, quartzose, argillaceous, streaked with lighter colored quartz silt that occurs in part as highly contorted lenslike bodies; bentonite, 0.03-foot-thick, pale-yellowish-brown, at base; FOSSILS - upright reed? molds	0.8
10.	Lignite, brownish-black	0.4
9.	Shale, dark-olive-gray to dark-gray, slightly silty to very silty, weathers flaky; FOSSILS - reed? molds (some upright)	1.7
8.	Siltstone, yellowish-gray, well-cemented, quartzose, laminated to gently cross-laminated, iron-stained, in lensing beds, with dark-gray silty shale partings; FOSSILS - upright reed? molds, carbonized plant fragments	0.4

7.	Lignite grading upward into lignitic shale, and carbonaceous shaly siltstone, brownish-black to dark-gray.	1.5
6.	Siltstone, dark-yellowish-brown to light-olive-gray, quartzose, argillaceous, in part shaly; FOSSILS - upright reed? molds	3.4
5.	Sandstone, light-olive-gray, quartzose, carbonaceous, poorly cemented, laminated; upper part dark yellowish orange to moderate yellowish brown, gently cross-bedded; FOSSILS - upright reed? molds, tree trunk mold .	0.8
4.	Lignite and lignitic shale, black to dark-gray.	0.5
3.	Shale, dark-olive-gray, silty, carbonaceous, weathers flaky, lignitic at base, thin lignite seam at center; FOSSILS - carbonized plant remains	1.5
2.	Siltstone, olive-gray, argillaceous, with contorted bedding; FOSSILS - carbonized plant debris, reed? molds.	1.1
1.	Shale, dark-olive-gray, silty, carbonaceous, weathers flaky, limonite- and jarosite-stained; FOSSILS - carbonized plant remains	4.2
	Thickness of exposed part of Dakota Formation	28.2
	Total thickness of measured section	70.9

Description of Section Measured at STOP 2

CARLILE SHALE

Fairport Chalk Member

		Feet
52.	Chalky limestone, weathered pale yellowish gray, highly fractured . . .	0.4
51.	Shaly chalk and chalky limestone; chalk weathered yellowish gray, soft, laminated, with very thin light-gray bentonite seam near base and deeply weathered bentonite seam at top; limestone in four concretionary layers, weathered grayish orange to very pale orange, hard, resistant, fossiliferous; FOSSILS - *Inoceramus cuvieri*, *I. labiatus*, *Collignoniceras woollgari*, baculitids? (recrystallized), *Ostrea congesta*, large pelecypod-bored log	5.2
	Thickness of exposed part of Fairport Chalk Member	5.6

GREENHORN LIMESTONE

Pfeifer Shale Member

50.	Chalky limestone (Fencepost limestone bed), weathered grayish orange with limonite stain through center of lower 0.7 foot, resistant, speckled; FOSSILS - *Inoceramus labiatus*, *Collignoniceras woollgari*, arthropod burrows	1.0
49.	Shaly chalk, and chalky limestone; chalk weathered pale grayish orange, breaks blocky, bedding planes limonite stained; lower bed of limestone dark grayish orange, speckled, very even; nodular limestone layers are concretionary, grayish orange to dark yellowish orange, contain few fossils, upper nodules with central layer of skeletal limestone; FOSSILS - *Inoceramus labiatus*, arthropod burrow, fish scales.	5.1
48.	Bentonite and gypsum ("sugar sand"); bentonite nearly white, gypsum granular, dark yellowish orange	0.36
47.	Shaly chalk and chalky limestone; chalk olive black weathering moderate yellowish brown to grayish orange, tough, laminated, speckled, characterized by chalky lenses filled with *Inoceramus* fragments; limestone olive gray weathering dark grayish orange, mostly in nodular layers - some at least partly concretionary, others with relict bedding, contain abundant whole and fragmentary *Inoceramus*; FOSSILS - *Inoceramus labiatus* *I. cuvieri*, fish remains.	6.6

46.	Chalky limestone, olive-gray, weathering grayish orange, speckled, resistant, very even bedding surfaces; FOSSILS - *Inoceramus labiatus*.	0.25
45.	Shaly chalk and chalky limestone; chalk like that in 47 with very thin lenses of skeletal limestone in upper 1 foot; limestone occurs in five nodular layers, olive-black (fresh) to pale-grayish-orange (weathered), with abundant whole and fragmentary *Inoceramus*, limonite commonly stains centers of limestone bodies, nodules in layer near center of unit laminated in lower part; FOSSILS - *Inoceramus labiatus*, *Hedbergella*	7.0
	Total thickness of Pfeifer Shale Member	20.3
	Jetmore Chalk Member	
44.	Chalky limestone, weathered yellowish gray, resistant, speckled, limonite-stained; FOSSILS - *Inoceramus labiatus*, smooth baculitid molds, arthropod burrows	1.15
43.	Shaly chalk and chalky limestone; chalk like that in 47, with very thin lenses of hard skeletal limestone in lower part; nodular limestone layer pale olive gray weathering pale grayish orange, with many *Inoceramus* fragments; limestone bed pale olive to pale grayish orange, mostly speckled, partly dense hard rock; FOSSILS - *Inoceramus labiatus*, fish remains	2.95
42.	Limestone and shaly chalk; limestone dark olive gray weathering pale grayish yellow to pale grayish orange, hard, brittle, slight petroliferous odor, resistant, with abundant whole *Inoceramus labiatus*, local concentrations of shell debris, and with sparse burrow structures; similar to that in 47, with abundant shells of *I. labiatus* and lenses of skeletal limestone; FOSSILS - *I. labiatus*, smooth baculitid.	3.2
41.	Shaly chalk and chalky limestone; chalk olive black weathering light olive gray, tough, laminated, speckled, chalk in upper 2 to 3 feet crowded with shells of *Inoceramus* and very thin lenses of skeletal limestone; limestone dark olive gray, mostly weathered very pale orange or pale grayish orange, mostly hard, resistant, most beds extensively burrow-mottled, limonite stains mark centers of most beds; FOSSILS - *Watinoceras reesidei*, *Inoceramus labiatus*, fish remains, burrow structures	13.5
	Total thickness of Jetmore Chalk Member	20.8
	Hartland Shale Member	
40.	Shaly chalk, olive-black, tough, laminated, speckled, with numerous harder nonlaminated, burrow-mottled layers; FOSSILS - *Inoceramus pictus*.	13.3
39.	Bentonite, nearly white, weathering dark yellowish orange, biotic, slightly silty.	0.5
38.	Shaly chalk, like that in 40; FOSSILS - *Inoceramus pictus*?, fish remains, burrow structures.	2.8
37.	Chalk, olive-gray, extensively burrowed, especially at base; FOSSILS - fish remains, *Inoceramus pictus*, burrow structures.	0.3
36.	Shaly chalk, olive-black, tough, laminated, well-jointed, with very thin lenses of hard skeletal limestone and one lensing chalk layer; FOSSILS - *Inoceramus pictus*	2.6
35.	Chalky limestone, olive-gray, relatively hard, speckled; FOSSILS - *Inoceramus pictus*, smooth baculitid molds, *Pteria* sp., *Kanabiceras kanabense*, *Sciponoceras gracile*	0.2-0.6
34.	Shaly chalk, olive-black, tough, laminated, speckled; bentonite, 0.3-foot-thick, light-brownish-gray to dark-yellowish-orange.	1.6-2.0
33.	Chalk, light-olive-gray to medium-gray, relatively hard, tough, much burrowed, sparse pyrite in burrows; FOSSILS - burrow structures, *Inoceramus pictus*	0.7

32.	Shaly chalk, like 34, with very thin lenses of skeletal limestone in lower 2.0 feet and two beds of chalk, the upper extensively burrowed, near top of unit; FOSSILS - *Inoceramus pictus*	4.9
31.	Bentonite, yellowish-gray weathering grayish yellow to dark yellowish orange.	0.2
30.	Shaly chalk, like 34, with scattered very thin lenses of skeletal limestone; bentonite is yellowish gray to dark yellowish orange; FOSSILS - *Inoceramus pictus*	1.3
	Total thickness of Hartland Shale Member	28.4

Lincoln Limestone Member

29.	Shaly chalk and limestone; shale like 34, with numerous limestone laminae; limestone pale yellowish brown, hard, skeletal, with petroliferous odor, in part gently cross-laminated; layer of weathered marcasite nodules in lower half; FOSSILS - *Inoceramus pictus*, *Squalicorax*, *Hedbergella*	2.0
28.	Shaly chalk, olive-black weathering dark yellowish brown to grayish orange, tough, laminated, speckled, with scattered thin lenses of fine-grained skeletal limestone and a single bed of olive-gray chalk; six bentonite seams are mostly dark yellowish orange; FOSSILS - fragments of *Inoceramus*, fish bones	4.5
27.	Shaly chalk, like 28, with scattered very thin lenses of hard, brittle, skeletal limestone and two dark-yellowish-orange bentonite seams; FOSSILS - *Inoceramus pictus*, fish bones, worm castings.	5.0
26.	Bentonite, dark-yellowish-orange.	0.2
25.	Shaly chalk, like 34, with very thin lenses of hard, brittle, skeletal limestone that has a petroliferous odor where fresh; FOSSILS - *Inoceramus pictus*, cirriped, fish bones.	0.8
24.	Bentonite, dark-yellowish-orange.	0.27
23.	Shaly chalk, like 34; FOSSILS - *Inoceramus pictus*, fish remains	1.7
22.	Bentonite, yellowish-gray weathering dark yellowish orange.	0.15
21.	Shaly chalk, weathered light gray to grayish orange, soft, laminated, speckled, with a few very thin lenses of hard skeletal limestone that has a petroliferous odor where fresh; FOSSILS - *Inoceramus pictus*, *Stramentum* sp., *Ostrea* sp., unidentified ammonite, fish remains	1.2
20.	Chalky limestone, weathered light brown to grayish orange, weathering to very thin beds or laminae; FOSSILS - *Inoceramus pictus*, 2 unidentified ammonites (molds).	0.3
19.	Shaly chalk, middle part olive-black, remainder weathered dark yellowish brown to grayish orange, tough to soft, laminated, speckled; FOSSILS - *Inoceramus pictus*, fish remains	3.1
18.	Chalky limestone, light-olive-gray weathering dark yellowish orange, with limonite stain through center of bed; FOSSILS - fish remains	0.5
17.	Shaly chalk, weathered grayish orange, soft, laminated, speckled, with numerous very thin lenses of skeletal limestone and a nearly white, dark-yellowish-brown-weathering bentonite at top; FOSSILS - *Inoceramus* fragments and prisms, fish remains.	0.7
16.	Skeletal limestone, pale-yellowish-brown to light-olive-gray weathering dark yellowish orange, hard, brittle, petroliferous odor, thinly laminated to gently cross-laminated, some quartz grains, weathered pyrite nodules near top; basal 0.25 foot conglomeratic, with quartz grains, bentonite pebbles, fish teeth and bones; FOSSILS - *Inoceramus pictus*, fish remains, *Ostrea beloiti*, *Hamites*? sp., unidentified ammonites, cirriped plates, coprolites	0.9
	Total thickness of Lincoln Limestone Member	21.3
	Total thickness of Greenhorn Limestone	90.8

GRANEROS SHALE

15.	Shale, medium-dark-gray weathering dark yellowish gray, slightly silty, thinly laminated	1.7
14.	Bentonite (bentonite marker bed), pale-grayish-yellow weathering dark yellowish orange, slightly silty.	0.7
13.	Shale, like 15, with very thin lenses of skeletal limestone and calcareous quartz siltstone in upper 0.5 foot; FOSSILS - *Inoceramus* sp., *Ostrea beloiti*.	0.9
12.	Calcareous sandstone, weathered moderate yellowish brown to grayish orange, quartzose, very fine grained, silty, thinly laminated to gently cross-laminated	0.3
11.	Shale, dark-gray, slightly silty, jarosite-stained, with specks of carbonaceous matter, thinly laminated, weathers flaky; FOSSILS - *Ostrea beloiti*, fish scales.	7.8
10.	Calcareous sandstone, dark-greenish-gray weathering dark yellowish orange, quartzose, thinly bedded, tightly cemented, very hard; FOSSILS - *Ostrea beloiti*	0.3
9.	Shale, olive-gray, silty, thinly laminated, weathers flaky, with thin laminae of quartz silt, specks of carbonaceous matter, jarosite and some limonite staining	0.65
8.	Skeletal limestone, light-olive-gray weathering dark yellowish orange, quartz sandy, some rounded bone pebbles, crowded with shells of *Ostrea*; FOSSILS - *Ostrea beloiti*, *Inoceramus* sp., fish teeth.	0.3
7.	Shale, medium-dark-gray to olive-gray, silty, thinly laminated, weathers flaky, jarosite-stained, lenses of very fine grained quartz sandstone in basal 1 foot; two bentonite beds in upper 0.7 foot are very pale orange to light olive gray; FOSSILS - *Inoceramus* sp.	3.1
6.	Calcareous sandstone, dark-greenish-gray weathering dark yellowish orange, quartzose, very fine grained, thinly laminated to gently cross-laminated, obscurely ripple-marked; FOSSILS - fish scales.	0.4
5.	Shale, medium-dark-gray, slightly silty, thinly laminated, weathers flaky, with specks of carbonaceous matter, jarosite-stained, with two very thin beds and many thin laminae of quartz silt; bentonite seam is light olive gray.	1.6
4.	Sandstone, weathered dark yellowish orange, quartzose, thinly laminated to gently cross-laminated, ripple-marked, limonitic, gypsiferous. . . .	0.2
3.	Shale, like 5, with two bentonite seams, the upper with sparse marcasite nodules, light-olive-gray	1.0
2.	Sandstone, light-olive-gray, quartzose, silty, thinly laminated to gently cross-laminated, ripple-marked, jarosite-stained, with specks and flakes of carbonaceous matter; FOSSILS - *Callistina lamarensis*, *Parmicorbula? hillensis* var., *Ostrea* sp., fish scales	0.15
1.	Shale, like 7, with numerous very thin beds and lenses of light-olive-gray thinly laminated quartzose siltstone; subaqueous plastic flow structure in argillaceous very fine grained silty sandstone layer near top of unit; FOSSILS - *Callistina lamarensis*.	3.0
	Thickness of exposed part of Graneros Shale	22.1
	Total thickness of measured section	118.5

Description of Section Measured at STOP 3

CARLILE SHALE

Fairport Chalk Member

		Feet
26.	Marly chalk, weathered grayish orange to dark yellowish orange, silty, relatively soft, tough, weathers blocky to crumbly, speckled, silt in this bed and similar beds below is calcareous.	0.8
25.	Shaly chalk, weathered dark yellowish orange to grayish orange, soft, laminated, speckled; FOSSILS - *Inoceramus cuvieri*, *Stramentum* n. sp., *Proboscina* n. sp.	6.6
24.	Marly chalk, weathered dark yellowish orange, silty, soft, blocky, speckled.	0.15
23.	Bentonite and gypsum; upper bentonite is 0.1 foot thick, light gray to light olive gray; lower bentonite is pale yellowish brown to dark yellowish orange; bentonites separated by 0.05 foot of prismatic gypsum and 0.1 foot of shaly chalk; dark-yellowish-orange granular gypsum lies at top	0.4
22.	Shaly chalk, olive-gray weathering light olive gray to medium light gray, soft, tough, laminated; bentonite is 0.07 foot thick, pale yellowish brown to dark yellowish orange; FOSSILS - *Inoceramus cuvieri*, *Ostrea congesta*, *Proboscina* n. sp., shark tooth.	2.9
21.	Marly chalk, olive-gray weathering light olive gray, soft, tough, speckled, silty, weathers blocky to crumbly	0.5
20.	Shaly chalk, light-olive-gray weathering light gray to yellowish gray, soft, tough, laminated, speckled.	0.9
19.	Marly chalk, light-olive-gray weathering yellowish gray, silty, very soft, very thinly bedded, breaks blocky, speckled	0.6
18.	Shaly chalk, like 20; FOSSILS - *Inoceramus cuvieri*, *Ostrea congesta*, *Serpula semicoalita*, *Proboscina* n. sp.	4.3
17.	Bentonite and gypsum, bentonite 0.02 foot thick, weathered moderate yellowish brown, overlain by 0.18-foot gypsum seam stained dark yellowish orange by iron oxide.	0.2
16.	Shaly chalk, like 20; bentonite near base is 0.05 foot thick, dark yellowish orange.	3.0
15.	Bentonite, light-olive-gray weathering dark yellowish orange to light brown	0.2
14.	Shaly chalk, like 20; FOSSILS - *Inoceramus cuvieri*, *Ostrea congesta*	2.8
13.	Chalky limestone, weathered dark yellowish brown to pale yellowish brown, silty, softer than unit 11, tough, speckled; silt is calcareous	0.35
12.	Shaly chalk, like 20; bentonite in upper half is 0.1 foot thick, dark yellowish orange; FOSSILS - *Inoceramus cuvieri*, *Ostrea congesta*, *Serpula semicoalita*	1.6
11.	Chalky limestone, weathered dark yellowish brown to grayish orange, medium-hard, speckled; FOSSILS - *Inoceramus cuvieri*	0.2
10.	Shaly chalk, like 20; FOSSILS - *Inoceramus cuvieri*, *Ostrea congesta*, *Serpula semicoalita*	1.8
9.	Chalky limestone, like 11; FOSSILS - *Inoceramus cuvieri*	0.2
8.	Shaly chalk, olive-gray weathering light gray, very tough, laminated, speckled, with very thin lenses of skeletal limestone near top; bentonite is 0.05 foot thick, weathered dark yellowish orange; FOSSILS - *Inoceramus cuvieri*, *Ostrea congesta*, *Collignoniceras woollgari*, *Actinocamax manitobensis*.	5.1

7. Chalky limestone, olive-gray to light-olive-gray weathering yellowish gray, medium-hard, tough, speckled; FOSSILS - *Inoceramus cuvieri*?, *Collignoniceras woollgari* 0.5

6. Shaly chalk, like 8, weathering platy, one layer of closely spaced and two layers of widely spaced concretionary nodules of olive-gray chalky limestone; FOSSILS - *Inoceramus latus*?, gastropod mold. 6.0

5. Chalky limestone, weathered yellowish gray to dark yellowish orange, medium-hard, resistant, speckled, top 0.08 foot separated from main bed by seam of bentonitic? gypsum; FOSSILS - recrystallized baculitids? 0.55

4. Gypsum, nearly white, iron-stained, granular, bentonitic. 0.25

3. Bentonite, nearly white, weathered dark yellowish orange. 0.3

2. Shaly chalk and chalky limestone; chalk like 8; limestone concretionary in three or four layers, olive-gray weathering yellowish gray, medium-hard, speckled, centers commonly iron stained, parallel to bedding; FOSSILS - *Inoceramus labiatus*, *Collignoniceras woollgari*, fish scales . 4.9

Thickness of exposed part of Fairport Chalk Member 45.10

GREENHORN LIMESTONE

Pfeifer Shale Member

1. Chalky limestone (top of Fencepost limestone bed), not measured.

Description of Section Measured at STOP 4

CARLILE SHALE

Blue Hill Shale Member Feet

29. Shale, light-olive-gray weathering yellowish gray, silty, blocky, weathers flaky; FOSSILS - fish remains. 3.5

28. Shale and concretions, shale similar to 29; concretions olive-gray weathering dark yellowish orange to grayish red, calcareous, septarian; FOSSILS - *Collignoniceras hyatti*, *Inoceramus flaccidus*. 4.0

27. Shale, light-olive-gray, very slightly silty, blocky to fissile, weathers flaky. 8.7

26. Shale and concretions; shale light olive gray, slightly silty, weathers flaky; concretions olive-gray weathering grayish red, pale brown and dark yellowish orange, weakly calcareous, clay-ironstone type; FOSSILS - *Inoceramus flaccidus*?, *Collignoniceras hyatti*? (juvenile) *Scaphites carlilensis* 1.9

25. Shale, dark-gray to light-olive-gray, weathering medium gray, very slightly silty, blocky to fissile, weathers flaky, jarosite-stained, much selenite; FOSSILS - *Collignoniceras hyatti*? (juvenile), *Inoceramus* sp. (juvenile), *Yoldia* sp., *Inoceramus cuvieri*? 28.1

Thickness of exposed part of Blue Hill Shale Member 46.2

Fairport Chalk Member

24. Calcareous shale, olive-gray weathering light olive gray, silty, soft, somewhat chalky in lower part, with small selenite crystals; FOSSILS - *Inoceramus* sp.. . . . . 7.7

23. Marly chalk, olive-gray weathering light olive gray, silty, speckled, medium-hard, breaks blocky; silt in this and similar beds below is calcareous; FOSSILS - *Inoceramus* n. sp. 0.7

22.	Shaly chalk, olive-gray weathering light olive gray, soft, laminated, speckled, less chalky in uppermost part, with very thin lenses of skeletal limestone in upper half; bentonite? is 0.01 foot thick, nearly white, hard; FOSSILS - *Collignoniceras woollgari*, *Inoceramus latus*, *I. cuvieri*, *Serpula tenuicarinata*, *Ostrea congesta*.	16.9
21.	Marly chalk, like 23; FOSSILS - *Inoceramus* sp..	0.55
20.	Shaly chalk, olive-gray weathering medium gray, tough, laminated, speckled, much calcareous silt in uppermost part, with ferruginous zone 0.05-foot thick lying 0.2 foot below top; bentonite is 0.05 foot thick, nearly white, weathering dark yellowish orange; FOSSILS - *Collignoniceras woollgari*, *Inoceramus cuvieri*.	4.7
19.	Marly chalk, olive-gray weathering light olive gray, silty, soft, tough, speckled; silt is calcareous; FOSSILS - *Inoceramus* sp..	0.3
18.	Shaly chalk, olive-gray weathering medium gray, tough, laminated, speckled; bentonite is 0.1 foot thick, nearly white weathering dark yellowish orange; FOSSILS - *Inoceramus* sp..	3.9
17.	Marly chalk, similar to 19.	0.15
16.	Shaly chalk, like 18; FOSSILS - *Ostrea congesta*, *Inoceramus latus*, *Inoceramus cuvieri*?.	4.6
15.	Marly chalk, similar to 19; FOSSILS - *Inoceramus cuvieri*?	0.3
14.	Shaly chalk, dark-gray weathering medium light gray, tough, laminated, speckled; bentonite is 0.1 foot thick, nearly white, weathering dark yellowish orange to grayish yellow; FOSSILS - *Ostrea congesta*, *Inoceramus latus*	1.2
13.	Marly chalk, similar to 19.	0.15
12.	Shaly chalk, olive-gray, tough, laminated, speckled, with very thin seam of dark-yellowish-orange bentonite at top; FOSSILS - *Serpula tenuicarinata*, *Inoceramus cuvieri*, *Actinocamax manitobensis*, *Stramentum* n. sp., *Inoceramus* sp.	1.2
11.	Marly chalk, like 19, thin-bedded; FOSSILS - *Inoceramus* sp.	0.3
10.	Shaly chalk, like 14, hard where fresh, much calcareous silt in uppermost beds; three very thin seams of bentonite, mostly weathered dark yellowish orange to grayish yellow; FOSSILS - *Inoceramus cuvieri*, *Inoceramus latus*, *Collignoniceras woollgari*	5.0
9.	Marly chalk, like 19; FOSSILS - *Inoceramus cuvieri*, *Stramentum* n. sp.	0.7
8.	Shaly chalk, like 14, with much calcareous silt; FOSSILS - *Inoceramus cuvieri*, *Inoceramus* sp., *Stramentum* n. sp..	1.2
7.	Marly chalk, like 11, with sparse marcasite nodules; FOSSILS - *Inoceramus cuvieri*, *Ostrea congesta*.	0.45
6.	Shaly chalk, like 14, much jointed; FOSSILS - *Ostrea congesta*, *Inoceramus cuvieri*, *I. latus*	5.9
5.	Marly chalk, light-olive-gray, soft, tough, speckled; FOSSILS - *Inoceramus cuvieri*	0.2
4.	Bentonite, yellowish-gray weathering dark yellowish orange.	0.15
3.	Shaly chalk, like 14; FOSSILS - *Ostrea congesta*	0.15
2.	Bentonite, nearly white weathering dark yellowish orange.	0.05
1.	Shaly chalk, like 14; FOSSILS - *Ostrea congesta*	2.2
	Thickness of exposed part of Fairport Chalk Member	58.7
	Total thickness of measured section	104.9

Description of Section Measured at STOP 5

		Feet
NIOBRARA CHALK		
	Fort Hays Limestone Member	
15.	Chalky limestone, much weathered and highly fractured	10.2
14.	Chalky limestone, mostly very light gray to pale-grayish-yellow, weathering pale yellowish orange, grayish orange, and dark yellowish orange; soft to medium-hard, tough, locally punky, commonly limonite-stained, bedding surfaces usually marked by worm? trails, worm? burrows common at several levels, rock very fine grained, porous; shaly chalk 16.6 feet above base is bentonitic, forms re-entrant; bentonite, olive-gray, biotitic, in seams 0.1 and 0.2 foot thick lying 3.7 and 5.5 feet below top, respectively; FOSSILS - *Inoceramus deformis*, *Ostrea congesta*, worm? and arthropod burrows	28.8
	Thickness of exposed part of Fort Hays Limestone Member	39.0
CARLILE SHALE		
	Codell Sandstone Member	
13.	Sandstone, yellowish-gray weathering dark yellowish orange, argillaceous, silty, shaly, soft, friable, streaked with medium-gray clay shale; FOSSILS - worm? burrows	0.4
12.	Sandstone and siltstone, basal part sandy siltstone, grading upward to very fine grained silty sandstone, light-olive-gray, weathering grayish yellow to yellowish gray, in part stained dark yellowish orange by limonite, quartzose, specked with small percentage of dark mineral grains, with irregularly spaced vertical joints, very thick bedded, cliff forming, poorly cemented, friable, burrow structures numerous throughout, FOSSILS - shark teeth, burrow structures.	10.7
11.	Siltstone, medium-gray to light-olive-gray, in part stained dark yellowish orange by limonite, very fine grained, quartzose, sandy, argillaceous, scattered shaly streaks, mostly poorly cemented, friable, but some thin layers are harder and cemented by iron oxide, unit less burrowed than unit 15; FOSSILS - shark teeth, burrow structures	13.9
	Total thickness of Codell Sandstone Member	25.0
	Blue Hill Shale Member	
10.	Siltstone and silty shale, transition from 9 to 11; shale medium dark gray to olive gray, blocky, streaked with siltstone; siltstone light olive gray streaked with dark-yellowish-orange limonite stains, very fine grained, quartzose, with wide range of clay admixture; sand occurs in vaguely lenslike bodies in some parts of unit.	5.1
9.	Shale and siltstone; shale dark gray weathering medium gray, stained in part by limonite and jarosite, streaked throughout with laminae, lenses, and very thin beds of light-olive-gray very fine grained quartz silt and sand; silt bodies more or less lenticular; basal part of unit contains calcareous septarian concretions, medium-dark-gray weathering yellowish gray, up to 2.8 feet thick and 5 feet in diameter; shale especially sandy in concretion zone	9.7
8.	Shale, dark-gray, blocky to fissile, weathers flaky, stained in part by limonite and jarosite, very silty throughout, streaked with very thin laminae and lenses of light-olive-gray quartzose sand and silt.	3.8
7.	Shale, like 8, slightly silty in lower part, siltier upward, transitional from 6 to 8	9.0
6.	Concretions and shale; concretions medium dark gray weathering yellowish gray, calcareous, septarian, highly irregular shapes, largest 1.8 x 1.4 feet; shale dark gray, blocky to fissile, weathers flaky, very slightly silty	1.7

5.	Shale, like 6, limonite-stained along joints and bedding with many jarosite-stained selenite clusters.	8.8
4.	Concretions and shale; concretions dark gray weathering yellowish gray to grayish orange, calcareous, septarian, granular-weathering matrix, highly irregular shapes, locally coalesced into masses several feet across; shale olive gray weathering dark yellowish orange to light brown, very finely sandy and silty.	1.3
3.	Shale, like 6, very finely sandy and silty in 3-foot-thick layer of blocky shale lying 25 feet above base, with locally abundant calcareous septarian concretions similar to those in unit 7.	31.2
2.	Concretions and shale; concretions dark gray weathering dark yellowish orange to yellowish gray, calcareous, septarian, highly irregular in shape with wart-like or tuberous surfaces; shale dark gray, blocky to fissile, weathers flaky, basal part and 0.8-foot-thick bed near center of unit finely sandy, blocky, does not weather flaky; FOSSILS - *Inoceramus flaccidus*, *Collignoniceras hyatti*, *Bellifusus willistoni*, *Lucina juvenis*	4.6
1.	Shale, dark-gray, blocky to fissile, weathers flaky, all silty with very thin layers and lenses of very fine quartzose sand near middle of unit, abundant small selenite crystals, scattered marcasite nodules; one calcareous septarian concretion, 1.1-foot-thick, dark-gray weathering dark yellowish orange; FOSSILS - (upper half of unit) *Ostrea congesta*?, *Inoceramus flaccidus*?, *Scaphites carlilensis*, *Yoldia* sp., *Collignoniceras hyatti*, ?*Proplacenticeras pseudoplacenta* (juveniles)	27.7
	Thickness of exposed part of Blue Hill Shale Member	102.9
	Total thickness of measured section	166.9

Description of Section Measured at STOP 6

PIERRE SHALE

Weskan Shale Member		Feet
37.	Covered interval in part greenish-brown shale that weathers black and contains sparse rusty-weathering siderite concretions; overlain by Ogallala Formation (Tertiary)	20.0
36.	Shale, greenish-black, soft, contains a few worm-burrowed small phosphatic concretions in lower part.	25.0
35.	Bentonite, white, nonswelling	1.0
34.	Shale, grayish-green, soft.	2.0
33.	Bentonite, reddish-brown, nonswelling	0.7
32.	Shale, very dark gray, soft, weathers light gray with a fine soft crust. Rarely, a rusty-weathering siderite concretion in lower part.	6.0
31.	Bentonite, cream to light-tan, granular texture, nonswelling with limonite and jarosite stain. Abundant gypsum in form of selenite	0.1
30.	Clay, plastic, olive-gray	0.2
29.	Bentonite, like unit 30	0.15
28.	Clay, like unit 29.	0.1
27.	Siderite concretions, about 0.4 x 1.5 feet, weathering rusty reddish brown; some have cone-in-cone structure. Almost continuous layer	0.4
26.	Shale, dark-gray, soft, flaky, weathering light gray.	2.0
25.	Bentonite, like unit 30	0.5
24.	Shale, like unit 25	1.2

23.	Bentonite, like unit 30	0.5
22.	Clay, like unit 29.	0.25
21.	Bentonite, white.	0.03
20.	Clay, like unit 29.	0.4
19.	Shale, like unit 25, but with a few phosphate nodules at base	2.4
18.	Limestone, concretionary, shaly to laminated, dark-gray, weathering tan to rusty yellow, lenslike in bodies 1.0 x 20 feet or more; contains a few fossils	1.0
	Thickness of measured part of Weskan Shale Member	63.9
	Sharon Springs Shale Member	
17.	Bentonite, white, nonswelling	0.02
16.	Shale, black, hard, hackly, does not form buttresses.	3.0
15.	Bentonite, like unit 16; also horizon of gray limestone concretions about 0.3 foot by 1.0 foot.	0.5
14.	Shale, like unit 15	1.3
13.	Bentonite, like unit 16	0.1
12.	Shale, like unit 15	2.0
11.	Bentonite, like unit 16	0.02
10.	Shale, dark-brownish-black, flaky to papery, abundant scales and other remains of fish, weathers grayish brown and in thicker units, weathers to form buttresses.	0.3
9.	Shale, like unit 9 with eight layers of dark-bluish-gray-weathering phosphate nodules. Some nodules appear as brown shale with concentric bands or rinds of gypsum. Most nodules contain abundant fish scales, bones, and pellets that may be fecal pellets. Four thin streaks of bentonite. These beds have been interpreted as claystone concretions by Elias and by Landis.	3.5
8.	Bentonite, cream to light-tan, nonswelling, granular texture.	0.25
7.	Shale, like unit 9 with five streaks of light-gray bentonite.	3.7
6.	Shale, like unit 9 with gray, tan-weathering limestone 0.8 x 3.0 x 5.0 feet lying 6 feet above base, and dark-gray limestone concretion with tan cone-in-cone structure 12 feet above base	17.0
5.	Limestone concretions, septarian, about 3.0 x 9.0 feet, with thick veins of light-brown calcite.	3.0
4.	Shale, like unit 9 except riddled with veins of gypsum, jarosite and limonite. Sparse, dark-gray, white-weathering, dense limestone concretions about 0.6 foot x 1.5 feet at 10, 13, and 15 feet above base. Concretions are of irregular shape and have 0.02-foot crusts of gypsum. At 18 feet above base is a zone of 1.0-foot and 2.0-foot gray, sparsely fossiliferous septarian concretions	25.0
3.	Bentonite, cream, nonswelling, granular, stained with jarosite and limonite and containing abundant gypsum	0.2
2.	Shale, like unit 9. Contains limestone concretions 13 to 21 feet below top. Lower 28 feet poorly exposed or covered	41.5
1.	Bentonite	0.4
	Thickness of exposed part of Sharon Springs Shale Member	101.8
	Total thickness of measured section	165.7

Description of Section Measured at STOP 7

NIOBRARA CHALK

Smoky Hill Chalk Member		Feet
34.	Chalky limestone, weathered pale yellowish orange to dark yellowish orange, punky to brittle, speckled, bed edges rounded, unit forms cap rock on cliff; FOSSILS - fish scales.	3.8
33.	Chalk, much weathered, grayish-orange to dark-yellowish orange, abundant gypsum along joints and bedding produces ragged face, four prominent partings are probably weathered seams of bentonite, lowest with large, hollow limonite nodules; unit forms part of cliff.	5.2
32.	Bentonite and gypsum; weathered very dark yellowish orange, gypsum adjacent to bentonite comprises most of unit.	0.4
31.	Chalk, much weathered, grayish-orange to dark-yellowish-orange, lower part much stained by limonite; unit forms part of cliff, steep and spally in water courses; less steep, softer and flaky on spurs; prominent parting is probably weathered bentonite seam	2.5
30.	Shaly chalk or soft chalky limestone, medium- to dark-yellowish-brown, weathering pale to dark yellowish orange, tough, appears to be nonlaminated or poorly laminated but laminae are weathered into relief locally, speckled; this is highest little-weathered unit in section; two prominent partings in lower half are probably weathered bentonite seams, upper one has large limonite nodules, some of which have marcasite cores; sparse limonite nodules also lie 1.2 feet below top; unit crisscrossed by veins of gypsum; FOSSILS - *Inoceramus platinus*?, *Ostrea congesta*	5.4
29.	Bentonite, nearly white, weathering dark yellowish orange, 0.1-foot-thick, with sparse marcasite nodules, and with seams of limonite and gypsum above and below.	0.17
28.	Shaly chalk or soft chalky limestone, medium-dark-gray to medium-light-gray, stained light brownish gray to grayish orange, tough, laminated, speckled; unit forms steep, spalling slope; bentonite near middle is 0.1 foot thick, grayish orange; prominent parting below bentonite is probably weathered bentonite; gypsum-filled joints common.	4.1
27.	Bentonite, yellowish-gray, 0.2-foot-thick, with seam of coarsely crystalline gypsum above and below	0.23
26.	Shaly chalk, very light olive gray, weathering moderate yellowish brown to grayish orange, tough, laminated, speckled, softer and somewhat flaky where slightly weathered, in part with hackly surface and intensively burrowed appearance; seams of gypsum crisscross unit; unit caps one of tallest pinnacles	1.2
25.	Bentonite, grayish-yellow weathering dark yellowish orange, bedding surfaces limonitic, very thin seam of granular gypsum at top of unit and locally beneath bentonite	0.11
24.	Chalky limestone, light-olive-gray weathering grayish orange to dark yellowish orange, tough, mostly nonlaminated but distinctly bedded, speckled, lower 2.25 feet with rough surface owing to intensive burrowing that produced a mottled appearance; three partings marked by reentrants may be weathered bentonite seams, lowest marked by continuous ferruginous-gypsiferous streak; FOSSILS - *Ostrea congesta*, *Inoceramus* sp.	3.9
23.	Bentonite, 0.08-foot-thick, nearly white weathering dark yellowish orange with ferruginous seam at top of unit	0.1
22.	Chalky limestone, very light olive gray weathering grayish orange to moderate yellowish brown, tough, nonlaminated, speckled; FOSSILS - *Ostrea congesta*	1.3

21.	Shaly chalk, medium-olive-gray to very light olive gray weathering grayish orange to very pale orange, tough, laminated, speckled, lower 0.4 foot with hackly surface; FOSSILS - *Inoceramus platinus*?, *Ostrea congesta*, fish remains.	1.15
20.	Bentonite, 0.05-foot-thick, very pale orange; seams of limonite and gypsum bordering bentonite projecting from slope.	0.11
19.	Shaly chalk, similar to 21, with hackly surface; softer and flaky where partly weathered; zone 0.3 to 0.6 foot above base tougher, nonlaminated, caps a few pinnacles; three very thin limonitic seams of bentonite above cap rock zone; FOSSILS - *Inoceramus* sp., *Ostrea congesta*.	2.6
18.	Shaly chalk and bentonite; chalk similar to 21, with darker colored disk-like patches of non-speckled rock that may have been burrowed; lower part of unit harder, caps numerous pinnacles; unit softer and flaky where partly weathered; bentonite at base 0.1 foot thick, yellowish gray to nearly white; bentonite near middle of unit 0.01 foot thick, limonitic; bentonite at top of unit 0.08 foot thick, pale greenish yellow, sandwiched between seams of jarosite, limonite, and gypsum; FOSSILS - *Inoceramus* sp., *Ostrea congesta*, fish scales	1.8
17.	Shaly chalk, like 21, with highly burrowed appearance; unit softer and flaky where partly weathered; lower 0.5 foot harder, caps numerous pinnacles; FOSSILS - *Ostrea congesta*, *Inoceramus* sp.	1.45
16.	Bentonite, 0.01-foot-thick, pale-greenish-yellow weathering dark yellowish orange, sandwiched between seams of olive-gray granular gypsum.	0.05
15.	Shaly chalk and chalky limestone; chalk light olive gray weathering dark yellowish orange to pale yellowish orange, tough, irregularly laminated, speckled, softer and flaky where partly weathered; limestone light olive gray weathering grayish orange to medium yellowish orange, very irregularly laminated, tough, speckled, apparently much burrowed, caps some pinnacles; unit crisscrossed sparingly by seams of gypsum; FOSSILS - *Ostrea congesta*, fish remains.	2.15
14.	Shaly chalk and bentonite, chalk dark yellowish brown to pale yellowish brown weathering grayish orange to pale yellowish brown, tough, very irregularly laminated, speckled; unit possibly much burrowed, weathers softer and flaky; five very thin ferruginous-gypsiferous, dark-yellowish-orange bentonite seams, none more than 0.03 foot thick, middle seam streaked moderate reddish brown; unit crisscrossed by seams of gypsum; FOSSILS - large coprolite	2.0
13.	Shaly chalk, olive-gray to medium-greenish-gray, stained dark gray to light brownish gray, tough, laminated, speckled; laminae near top highly irregular, unit possibly burrowed; forms steep, spalling face where fresh; softer and flaky with more gentle slope where partly weathered; unit locally much crisscrossed by seams of gypsum.	6.1
12.	Limonite and gypsum, dark-yellowish-orange, discontinuous, with thin clay streak in center; probably weathered bentonite.	0.01-0.02
11.	Shaly chalk, olive-gray to light-olive-gray, stained medium dark gray, tough, laminated, speckled, locally forms steep spalling slope, softer and flaky where partly weathered; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*.	1.8
10.	Bentonite, 0.03-foot-thick, dark-yellowish-orange	0.03
9.	Shaly chalk, similar to 11; FOSSILS - *Inoceramus platinus*?, *Ostrea congesta*	1.85
8.	Shaly chalk and bentonite; chalk similar to 11; bentonite at base is 0.11 foot thick, yellowish gray, with associated limonite and jarosite; second bentonite seam is 0.05 foot thick, dark yellowish orange, ferruginous, with minute selenite and biotite grains; bentonite at top is 0.03 foot thick, dark yellowish orange, with associated granular to powdery gypsum; FOSSILS - fish scales.	1.24

7.	Shaly chalk, like 11, but surficially stained black to bluish gray, lenticular soft chalky limestone body in upper one-half caps low pedestal on one stream spur; FOSSILS - *Inoceramus platinus*?, *Ostrea congesta*.	5.4
6.	Limonite and gypsum, dark-yellowish-orange, central part pale yellowish orange with local masses of limonite up to 0.2 foot thick and 1.5 feet across and lenses of marcasite where section is fresh; unit is probably weathered bentonite	0.13
5.	Shaly chalk, olive-gray to dark-yellowish-brown stained pale orange, tough, laminated, speckled, weathers soft and flaky; seams of gypsum along bedding and low-dipping joints.	1.1
4.	Limonite and gypsum, dark-yellowish-orange and nearly white, respectively, gypsum powdery, unit contains oblate spheroidal limonite masses; unit is probably weathered bentonite.	0.09
3.	Shaly chalk, light-olive-gray to yellowish-gray, weathering dark yellowish orange to grayish orange, soft, laminated, speckled, somewhat flaky, with small very thin lens of gilsonite? in upper part; FOSSILS - *Inoceramus platinus*?, *Ostrea congesta*.	7.65
2.	Limonite and gypsum seam, dark-yellowish-orange, gypsum coarsely crystalline, unit pinches and swells	0.06-0.1
1.	Shaly chalk, medium-olive-gray with dark-yellowish-orange stain where weathered, tough, laminated, speckled	2.3
	Thickness of exposed part of Smoky Hill Chalk Member	67.5
	Total thickness of measured section	67.5

Description of Section Measured at STOP 8

NIOBRARA CHALK

Smoky Hill Chalk Member

		Feet
32.	Shaly chalk and chalky limestone, highly oxidized, pale-yellowish-gray to very light gray, brittle and massive beds alternating with softer, tough, shaly beds, all speckled; shaly part poorly laminated, weathers flaky; two limonite partings may be weathered bentonite seams; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*, fish scales	10.2
31.	Bentonite, yellowish-gray, unit composed mostly of limonite and jarosite, forms deep re-entrant	0.06
30.	Chalky limestone, cap rock in cliffs and pinnacles, weathered color ranges from very pale orange and light gray to grayish orange with some nearly white beds near top; higher parts of unit blackened by lichens; rock relatively brittle, speckled, obscurely laminated, all but uppermost 4.4 feet more or less massive; generally cavernous, weathering with 6-foot-thick zone of especially conspicuous cavernous hollows lying approximately 5 to 11 feet below top; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*, burrow? structure.	15.8
29.	Chalk, weathered, wide range of pale coloration from very light gray to pale yellowish orange, tough, poorly and obscurely laminated, speckled, appears massive at distance but contains many seams of selenite lying parallel to bedding and marked locally by limonite-jarosite nodules; upper part of unit locally weathers cavernous; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*, fish remains	13.6
28.	Bentonite and gypsum, dark-yellowish-orange, limonitic, seam consists mostly of selenite.	0.02
27.	Chalk, weathered, mottled very light gray and very pale orange with five more or less continuous seams of selenite; very tough, obscurely laminated, speckled, weathers soft and flaky	0.9

26.	Bentonite and gypsum, dark-yellowish-orange, seam consists mostly of gypsum which locally thickens to 0.06 foot.	0.02
25.	Shaly chalk, weathered, light-gray to very pale orange, tough, very obscurely laminated, speckled, with three seams of prismatic selenite lying parallel to bedding and some platy selenite along joints and bedding; FOSSILS - *Inoceramus* sp., *Ostrea congesta*.	1.4
24.	Bentonite and gypsum, grayish-orange, seam consists mostly of prismatic selenite.	0.04
23.	Shaly chalk, weathered, light-yellowish-gray to pale-grayish-orange, somewhat mottled, obscurely laminated, speckled, tough, weathering softer and flaky, with 0.2-foot-thick lensing bed of chalk 1 foot above base; platy selenite abundant on slope; FOSSILS - *Inoceramus* sp., *Ostrea congesta*	2.15
22.	Gypsum, prismatic, forms conspicuous marker	0.03
21.	Shaly chalk, light-olive-gray with light-gray mottling, top 0.3 foot weathered grayish orange to light yellowish gray, like 23; 0.01-foot-thick layer of powdery gypsum lies 1.9 feet above base; FOSSILS - *Ostrea congesta*, *Inoceramus platinus*, *Clioscaphites choteauensis*, smooth baculitid, fish remains	2.7
20.	Gypsum, two layers of prismatic selenite separated by a limonite seam; unit forms conspicuous re-entrant	0.04
19.	Shaly chalk and chalk, light-olive-gray weathering very light gray, mottled, very tough, obscurely laminated, speckled; FOSSILS - *Inoceramus simpsoni*, *Inoceramus platinus*, *Clioscaphites choteauensis*, *Ostrea congesta*, smooth baculitid, fish remains.	0.55
18.	Bentonite, dark-yellowish-orange, with very thin seams of prismatic selenite and some powdery gypsum above and below.	0.08
17.	Shaly chalk, light-olive-gray weathering light gray, mottled with very pale brown, very tough, especially hard in upper 0.4 foot, all obscurely laminated, speckled, very fossiliferous; FOSSILS - *Ostrea congesta*, *Inoceramus platinus*, smooth baculitid	3.2
16.	Bentonite and gypsum; bentonite is 0.03 foot thick, moderate yellowish brown; seams of prismatic selenite above and below bentonite; unit forms conspicuous re-entrant.	0.09
15.	Shaly chalk, light-olive-gray to moderate-yellowish-brown, weathering pale olive gray with light-gray banding near top and darker banding in lower part, tough, obscurely laminated, speckled, softer and flaky in dark-banded part; FOSSILS - *Inoceramus platinus*, *Ostrea congesta* . .	4.65
14.	Bentonite and gypsum, bentonite is light brown, limonitic, unit composed mostly of granular and powdery gypsum	0.04
13.	Shaly chalk, light-olive-gray to moderate-yellowish-brown, weathering pale olive gray mottled with grayish orange; near base unit is tough and hard, blocky, grading upward to softer and flakier weathering rock, all speckled and obscurely laminated, with much powdery gypsum and some platy gypsum along joints and bedding planes; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*	1.45
12.	Gypsum, mostly white and powdery with a streak of limonite, probably a weathered bentonite seam.	0.02
11.	Shaly chalk, light-olive-gray weathering pale olive gray and locally mottled with light gray, with two darker bands in lower half; like 23; darker bands weather very soft and flaky; much powdery gypsum throughout; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*	9.6
10.	Bentonite, dark-yellowish-orange, less than 0.01 foot thick, sandwiched between seams of limonite and nearly white powdery gypsum, with scattered limonite nodules up to 0.1 foot thick and 0.7 foot across	0.04

9.	Shaly chalk, light-olive-gray to yellowish-gray mottled with light gray, like 23, with much powdery gypsum and a conspicuous gypsum parting 4.9 feet above base; FOSSILS - *Ostrea congesta*, *Inoceramus platinus*, baculitid? mold, fish remains	7.7
8.	Bentonite, nearly white to very pale orange, 0.02-foot-thick, sandwiched between seams of jarosite, limonite and powdery gypsum; scattered nodules of marcasite, largely weathered to limonite and jarosite, up to 0.23 foot thick and 2.3 foot across	0.05
7.	Shaly chalk, light-olive-gray weathering yellowish gray to grayish orange, like 23, with much powdery gypsum; FOSSILS - smooth baculitid, *Ostrea congesta*, *Inoceramus platinus*	2.35
6.	Bentonite, light-brown, slightly silty, with sparse limonite-jarosite nodules	0.01
5.	Shaly chalk, light-olive-gray to moderate-yellowish-brown, mottled, tough, laminated, speckled, with much powdery gypsum; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*, fish remains	4.2
4.	Shaly chalk, olive-gray to light-olive-gray, soft, laminated, speckled, unit conspicuously darker than adjacent units; FOSSILS - *Ostrea congesta*, fish remains.	0.5
3.	Shaly chalk, light-olive-gray, tough, laminated, speckled, with much powdery gypsum; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*, fish remains	1.15
2.	Bentonite, grayish-orange to grayish-yellow, with jarositic marcasite nodule.	0.01
1.	Shaly chalk, light-olive-gray mottled light gray, very tough, obscurely laminated, speckled, with much powdery gypsum; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*	2.65
	Thickness of exposed part of Smoky Hill Chalk Member	85.3
	Total thickness of measured section	85.3

Description of Section Measured at STOP 9

NIOBRARA CHALK

Smoky Hill Chalk Member

		Feet
59.	Chalk and shaly chalk, chalk weathered very pale orange to nearly white, evenly bedded, very thinly laminated in part, burrowed in part; shaly chalk, weathered grayish orange to dark yellowish orange; 0.02-foot-thick, light-brown bentonite lies near middle; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*	5.9
58.	Shaly chalk, weathered grayish orange, soft, laminated; bentonite, 0.08-foot-thick, lies 0.6 foot above base	1.6
57.	Chalk and shaly chalk, weathered very pale orange to dark yellowish orange, all soft, thick bed of chalk is laminated; FOSSILS - *Inoceramus platinus*, *Ostrea congesta*, fish remains	3.5
56.	Shaly chalk, lower 4 feet are olive gray to light olive gray, remainder dark yellowish brown, grayish orange and dark yellowish orange in upward succession, all soft, laminated, speckled, softer where weathered; two bentonite seams, each less than 0.01 foot thick; lower bentonite underlies 0.15-foot-thick seam of selenite; sparse limonite nodules in zone lying approximately 8 feet below top.	19.1
55.	Shaly chalk, weathered grayish orange, with beds of very pale yellowish gray to pale-yellowish-orange chalk at top and base of unit, soft, banded by limonite near top.	2.3

54.	Chalk, weathered grayish orange to pale grayish orange, lichen-covered, moderately hard, with numerous burrow structures; FOSSILS - *Inoceramus platinus*, *Inoceramus grandis*, *Ostrea congesta*	0.6
53.	Shaly chalk, olive-gray weathering grayish yellow to pale yellowish orange, soft, speckled, numerous powdery gypsum seams, limonite nodules at several levels with several zones of more resistant, massive ledge-forming chalk; harder beds are yellowish gray weathering grayish orange, laminated; unit very fossiliferous; FOSSILS - *Inoceramus platinus*, *Inoceramus grandis*, *Ostrea congesta*, burrow structures	12.8
52.	Chalk, medium-light-gray and shaly near base, yellowish-gray in upper part, weathering grayish orange, relatively hard, with sparse limonite nodules; FOSSILS - *Inoceramus grandis*, *Inoceramus platinus*?, *Ostrea congesta*.	1.9
51.	Bentonite and gypsum; bentonite is dark yellowish orange, gypsum powdery	0.02
50.	Shaly chalk, dark-yellowish-brown to light-olive-gray, soft, laminated; FOSSILS - *Inoceramus grandis*, *Inoceramus platinus*?, *Ostrea congesta*	0.42
49.	Bentonite, dark-yellowish-orange, slightly silty, selenite at top	0.06
48.	Chalk, weathered grayish orange, weathers flaky	0.17
47.	Bentonite and gypsum; unit is predominantly white powdery gypsum.	0.05
46.	Chalk, olive-gray weathering grayish yellow, grayish orange and dark yellowish orange, except for one hard bed that weathers shaly, especially at base; shaly part riddled with irregular-shaped chalk-filled burrow structures; partly limonitized marcasite nodules lie near top of unit; FOSSILS - *Inoceramus grandis*, *Inoceramus platinus*?, *Ostrea congesta*	2.4
45.	Shaly chalk and chalk, pale-olive-gray to moderate-yellowish-brown, slope forming, nonresistant, riddled with irregular chalk-filled burrow structures in zone lying 0.8 foot below top; many smaller cylindrical burrow structures in chalk in lower half; pelecypod shells fragmentary; FOSSILS - *Inoceramus* sp.	2.9
	Thickness of exposed part of Smoky Hill Chalk Member	53.7
Fort Hays Limestone Member		
44.	Chalky limestone, pale-yellowish-gray to light-olive-gray weathering pale grayish orange with lichen coating; this and similar units below relatively hard, cliff forming, porous; vertical calcite-filled rodlike burrow structures common near top; horizontal and irregular chalk-filled burrow structures common in lower half of unit; fragmentary *Inoceramus* shells common; FOSSILS - *Inoceramus deformis*, *Ostrea congesta*	2.6
43.	Bentonite, olive-gray, speckled with biotite?, selenitic.	0.03
42.	Chalk, yellowish-gray to pale-yellowish-gray, intensively burrowed.	1.0
41.	Shaly chalk, light-olive-gray to olive-gray, many irregular-shaped chalk-filled burrow structures; FOSSILS - *Inoceramus* sp. (fragments).	0.5
40.	Bentonite, light-olive-gray, stained grayish orange by limonite	0.07
39.	Chalky limestone, light-gray to light-olive-gray, weathering nearly white to pale grayish orange, lichen-covered where measured, shaly chalk zone near middle is riddled with threadlike and larger chalk-filled burrow structures; unit intensively burrowed throughout; FOSSILS - *Ostrea congesta*, *Inoceramus* (fragments)	4.3
38.	Bentonite?, light-olive-gray, speckled with biotite, shaly, streaked with chalk.	0.05
37.	Chalky limestone, weathered yellowish gray to nearly white or pale grayish orange, lichen-covered where measured, many small, vertical, calcite-filled, rodlike burrow structures near middle, larger burrow casts common; FOSSILS - *Inoceramus deformis* (fragments), *Ostrea congesta*.	4.8

36.	Shaly chalk, weathered light olive gray to pale yellowish brown or grayish orange, with very thin bentonite seam nearly at base and with rare small limonite nodules, many irregular-shaped chalk-filled burrow structures.	0.45
35.	Chalky limestone weathered pale yellowish gray to pale yellowish orange, lichen-covered where measured, 0.1-foot-wide limonite nodule near base, irregular-shaped chalk-filled burrow structures common in lower half; vertical calcite- and limonite-filled rodlike burrow structures abundant in middle part of unit; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*	2.95
34.	Bentonitic shale, light-olive-gray, slightly biotitic	0.13
33.	Chalky limestone, weathered pale yellowish gray to pale grayish orange, lichen-covered where measured,sparse vertical calcite- and limonite-filled burrow structures; shaly chalk forms re-entrant 0.3 foot above base; FOSSILS - *Inoceramus* sp. (fragments).	1.5
32.	Shaly chalk, light-olive-gray, argillaceous, with nearly white lenses of chalk, and with burrow structures near top.	0.08
31.	Chalky limestone, like 33, with numerous vertical calcite-filled and many irregular-shaped chalk-filled burrow structures; FOSSILS - *Inoceramus* fragments (probably *Inoceramus deformis*).	1.0
30.	Shaly chalk, light-olive-gray, argillaceous, intensively burrowed horizontally	0.1
29.	Chalky limestone, like 33, only mottled with light gray; scattered blebs of pyrite, some oxidized to limonite; many vertical calcite-filled rodlike burrow structures; many irregular-shaped chalk-filled burrow structures	2.4
28.	Shaly chalk and chalk, light-olive-gray weathering yellowish or pale yellowish gray, upper shaly part argillaceous, all with irregular-shaped chalk-filled burrow structures, chalk bed in middle with vertical calcite- or limonite-filled rodlike burrow structures; FOSSILS - *Inoceramus deformis* (mostly fragmentary), *Ostrea congesta*	1.15
27.	Bentonite, light-olive-gray, biotitic	0.05
26.	Chalky limestone, weathered pale yellowish gray to nearly white, lichen-covered where measured, shaly at base and in zone 1.4 feet below top, limonite nodule 0.8 foot above base, many irregular-shaped chalk-filled burrow structures above upper shaly zone, vertical calcite-filled rodlike burrow structures, sparse fragments of *Inoceramus*; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*	3.8
25.	Bentonite, light-olive-gray	0.05
24.	Chalky limestone, like 26, with some irregular-shaped chalk-filled burrow structures and pyrite- and calcite-filled rodlike burrow structures; FOSSILS - *Inoceramus* sp. (fragments).	2.0
23.	Shaly chalk, weathered light olive gray, stained dark yellowish orange by limonite, many irregular-shaped chalk-filled burrow structures; FOSSILS - *Inoceramus deformis* (whole), *Ostrea congesta*.	0.1
22.	Chalky limestone, like 26, with sparse irregular-shaped chalk-filled burrow structures; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*	1.7
21.	Bentonite, light-olive-gray, weathering dark yellowish orange, biotitic	0.1
20.	Chalky limestone, like 26, with sparse irregular-shaped chalk-filled burrow structures; FOSSILS - *Inoceramus* sp. (fragments), *Ostrea congesta*	2.2
19.	Bentonite, light-olive-gray, stained dark yellowish orange by limonite, biotitic, with sparse selenite crystals	0.05
18.	Shaly chalk, weathered light olive gray to yellowish gray, 0.1-foot-thick selenite seam 0.75 foot below top, sparse limonite nodules, upper part has irregular-shaped chalk-filled burrow structures; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*	1.55

17.	Chalky limestone, like 26, with 0.1-foot-thick shaly zone 0.4 foot below top; limonite nodules occur at base of unit; limonite-filled threadlike burrow? structures in lower part; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*.	1.6
16.	Chalky limestone, like 26, shaly at top and base, limonite nodules common at base; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*, *Serpula* sp.	2.9
15.	Chalk, weathered yellowish gray to moderate yellowish brown, middle part shaly and with many irregular-shaped chalk-filled burrow structures; pyrite- and limonite-filled rodlike burrow structures; FOSSILS - *Inoceramus deformis* (mostly whole), *Ostrea congesta*	1.4
14.	Chalky limestone, weathered pale yellowish gray to pale grayish orange or nearly white, lower 1 foot mottled with medium gray, with scattered blebs of pyrite most of which is partly limonitized, and vertical pyrite-filled rodlike burrow structures; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*.	2.9
13.	Shaly chalk, olive-gray to light-olive-gray, with many horizontal chalk-filled burrow structures; FOSSILS - *Inoceramus deformis* (mostly fragmentary).	0.3
12.	Chalky limestone, light-olive-gray with olive-gray shaly zone at re-entrant near top, many horizontal chalk-filled burrow structures; FOSSILS - *Inoceramus deformis*, (whole and fragmentary), *Ostrea congesta*	2.3
11.	Shaly chalk, olive-gray.	0.1
10.	Chalky limestone, weathered pale yellowish gray to grayish yellow, in part stained dark yellowish orange by limonite, lichen-covered where measured, upper part shaly with many irregular-shaped chalk-filled burrow structures; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*.	3.7
9.	Shaly chalk, olive-gray.	0.1
8.	Chalky limestone, like 14, limonite blebs scattered throughout, with irregular-shaped chalk-filled burrow structures, especially near middle and top of unit; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*.	4.3
7.	Chalky limestone, weathered yellowish gray, shaly at base and top, limonite blebs common near middle of unit, local manganese dendrites, many irregular-shaped chalk-filled burrow structures; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*.	5.5
6.	Chalky limestone, medium-gray to light-olive-gray weathering grayish orange and locally dark yellowish orange, some lichens, uppermost part shaly, base of bed cavernous, sparse limonite nodules near base, many irregular-shaped calcite-filled burrow structures; unit in part very thinly laminated and possibly cross-laminated, with scattered very thin lenses of skeletal limestone; FOSSILS - *Inoceramus deformis* (whole and fragmentary), *Ostrea congesta*.	4.5
5.	Chalky limestone, like 14, upper 1.3 feet light olive gray, some lichen cover, sparse limonite and pyrite nodules near top; all with irregular-shaped chalk-filled burrow structures, especially in upper 1.3 feet; FOSSILS - *Inoceramus deformis* (mostly fragmentary), *Ostrea congesta*. .	4.0
4.	Shaly chalk, dark-gray weathering light olive gray, forms prominent re-entrant	0.1
3.	Chalky limestone, weathered pale grayish orange to grayish orange, with limonite nodules in zone near middle; unit contains scattered irregular-shaped chalk-filled burrow structures and numerous vertical limonite-filled threadlike burrow structures; FOSSILS - *Ostrea congesta*	1.6
2.	Chalky limestone, like 14, some lichen cover; silty, especially at base; scattered limonite-filled rodlike burrow structures, many irregular-shaped chalk-filled burrow structures; FOSSILS - *Ostrea congesta* (fragments)	1.9
	Total thickness of Fort Hays Limestone Member	71.9

CARLILE SHALE

Blue Hill Shale Member

1.	Silty shale, dark-gray to olive-gray, with many irregular laminae and very thin beds of light-olive-gray quartzose siltstone; unit in sharp contact with unit 2	1.0
	Thickness of exposed part of Blue Hill Shale Member	1.0
	Total thickness of measured section	126.6

Description of Section Measured at STOP 10

NIOBRARA CHALK

Fort Hays Limestone Member

		Feet
12.	Chalky limestone, weathered very pale grayish orange to dark yellowish orange, weathers shaly in lower part, medium-hard, porous, caps hill at road cut, fossil fragments scattered throughout; FOSSILS - *Ostrea congesta*, on *Inoceramus deformis*, burrow structures	2.0
11.	Chalky limestone, weathered very pale grayish orange, dark-yellowish-orange where limonite stained, medium-hard, porous, fragments of *Inoceramus* scattered throughout; FOSSILS - *Ostrea congesta* on *Inoceramus deformis*.	4.7
10.	Chalky limestone, like 11, large burrow structures common throughout, minute burrows common near top, with *Inoceramus* fragments common near top of unit; FOSSILS - *Inoceramus deformis*, *Ostrea congesta*, burrow structures.	4.25
9.	Bentonite, medium-gray weathering grayish orange, calcareous, shaly, waxy.	0.15
8.	Chalky limestone, weathered pale grayish orange with nearly white surfaces, in part limonite-stained, weathers shaly between two beds, medium-hard, burrow structures throughout; basal bed thickens downward from minimum 1.8 feet to 6.0 feet, contains sparse limonite nodules; FOSSILS - worm? burrows, arthropod burrows.	3.2-7.4
	Thickness of exposed part of Fort Hays Limestone Member	14.3-18.5

CARLILE SHALE

Codell Sandstone Member

7.	Siltstone, yellowish-gray to light-olive-gray, very much limonite stained, soft where wet, hard and brittle where dry, quartzose, poorly bedded, breaks blocky, numerous burrow structures, streaked in part with medium-dark-gray shale, especially near middle of unit; upper 0.3 foot locally olive gray, argillaceous, and shaly; FOSSILS - burrow structures.	2.5
	Total thickness of Codell Sandstone Member	2.5

Blue Hill Shale Member

6.	Shale, medium-dark-gray, very silty throughout, with numerous irregular-shaped patches (filled burrows) of limonite-stained quartzose silt, color and texture are Blue Hill lithology	0.75
5.	Siltstone, argillaceous siltstone, and shale; siltstone is light olive gray, in part limonite and jarosite stained, and quartzose; argillaceous siltstone is olive gray, stained by jarosite and limonite, thinly and irregularly interlaminated with streaks of clay and has numerous burrow structures; shale is dark gray, very silty, contains very thin laminae of quartzose silt and many burrow structures; unit breaks blocky except for shale; all lithologic gradations from siltstone to shale; unit transitional between Blue Hill and Codell members, characterized by burrow structures	4.7

4.	Shale and siltstone, light-olive-gray to medium-dark-gray, with all intermediate varieties of color and texture; silt and clay intimately interlaminated in lensing layers and in part burrow mottled, blocky to fissile, hard and brittle where dry and fresh, in part limonite- and jarosite-stained	3.6
3.	Siltstone, light-olive-gray, soft, argillaceous, in two beds separated by a 0.3-foot-thick layer of dark-gray, blocky, very argillaceous siltstone or silty shale	0.7
2.	Shale and siltstone, medium-dark-gray to dark-gray to olive-gray; lithology completely gradational from moderately silty shale to siltstone; shale intimately interlaminated with or mottled by light-olive-gray laminae and lenses of quartzose silt, with silt predominating in some parts of unit; irregularly bedded layer of light-olive-gray siltstone, 0.2-foot-thick, lies 5 feet above base; unit stained in part by limonite and jarosite	9.9
1.	Shale, medium-dark-gray to dark-gray, fissile, weathers flaky, slightly silty to very silty, with numerous thin laminae and lenses of light-olive-gray siltstone; unit stained in part by limonite and jarosite	2.8
	Thickness of exposed part of Blue Hill Shale Member	22.5
	Total thickness of measured section	39.3